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EVALUATION OF THE EFFECTS OF FABRIC STRUCTURE AND RESIN TREATMENT ON TEAR STRENGTH AND OTHER PROPERTIES OF COTTON FABRICS

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service

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EVALUATION OF THE EFFECTS OF FABRIC STRUCTURE AND RESIN TREATMENT ON TEAR STRENGTH AND OTHER PROPERTIES OF COTTON FABRICS[1]

by

E. James Stavrakas and Milton M. Platt

INTRODUCTION

This is the third and final progress report concerning the change in tear strength of cotton fabrics occasioned by wet finishing treatments in general and resin treatment in particular.

Earlier progress reports are concerned with the following studies:

Part I[2], Phase 1 deals with the changes in tear strength of 10 commercial cotton fabrics at each stage of the wet finishing process; Part II[3], Phases 2, 3 and 4 are concerned respectively with an analysis of fabric structure as it relates to the observed changes in tear strength occasioned by resin treatment and a theoretical analysis of the mechanics of the tearing action, the effect of fabric geometry on tear strength, and the design of a series of experimental cotton fabrics that represent variations of four of the commercial fabrics studied in Phases 1 and 2.

Parts III and IV of the subject contract, constituting Phases 5 and 6 of the study, are reported herein. In accordance with Part III of the subject contract, the experimental fabrics designed in Phase 4 were manufactured, and control fabrics for each of the selected constructions were woven to duplicate as nearly as possible the yarn and fabric structures of the corresponding commercial fabrics examined in Phase 1. All fabrics were produced from selected bales of DPL cotton, which had been well blended prior to processing, thereby eliminating variability of fiber properties as a factor in the investigation.

In accordance with Part III, Phase 5, the fabrics have been evaluated for tear and other pertinent physical properties to determine the validity of the theoretical determinations of Phase 2. It should be noted that all of the fabrics had been desized, scoured, and bleached and were therefore tested in the so-called "prepared" or finished without resin state.

Each of the "prepared" fabrics were then treated with the resin formulations approved by the Contracting Officer's designated representative, and evaluated for tear strength and other pertinent properties such as tensile strength, abrasion resistance, and drapability in accordance with the requirements in Part IV, Phase 6. Thus the work outlined in Parts III and IV of the subject contract has been completed.

A detailed description of the experimental and control fabrics is contained in Table IV of Phase Report No. 2 published by the Agricultural Research Service as ARS 72-19, pp. 1-16, (1961). The variations or experimental fabrics corresponding to the four control fabrics are identified as follows:

Control	Variations
1	1A, 1B, 1C, 1D, 1E, 1F, 1G and 1H
2	2A, 2B, 2C, 2D, 2E, 2F
3	3A, 3B, 3C, 3D, 3E
4	4A, 4B, 4C, 4D, 4E, 4F, 5 and 5B

The original intent was to treat control 5 and its variations 5A and 5B separately. However, due to limitations imposed by the yardage available for this warp series, sample 5A was cancelled and it was deemed advisable to consider samples 5 and 5B as variations of control No. 4.

Earlier work[2] had revealed serious reductions in tear strength occasioned by the preparatory (desizing, scouring and bleaching) finishing treatments. Accordingly, it was deemed pertinent to the aims of this research to evaluate the tear strength of the controls and their experimental variations in the greige state. Thus all fabrics have been evaluated for tear strength at three stages; namely, greige, finished without resin, and resin treated.

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[1] A report of work done at Fabric Research Laboratories, Inc. under contract with the U. S. Department of Agriculture and authorized by the Research and Marketing Act of 1946. The contract is being supervised by the Southern Utilization Research and Development Division of the Agricultural Research Service.

[2] Phase Report No. 1 published by the Agricultural Research Service as ARS 72-18, pp. 1-22 (1961)

[3] Phase Report No. 2, published by the Agricultural Research Service as ARS 72-19, pp. 1-16 (1961)

DESCRIPTION OF TEST METHODS

At this point it seems appropriate to describe the test methods used for obtaining the data reported herein. All tests were performed in an atmosphere of 70° F. and 65% R. H., and samples were conditioned for a minimum of 24 hours prior to testing. Fabric width, weight, number of ends and picks per inch, ravel strip tensile, tongue tear, and yarn crimp determinations were carried out in accordance with ASTM Test Method D39 with the following variations, presented for each method.

RAVEL STRIP TENSILE TESTS

In this work all samples, with the exception of the warp specimens for warp series No. 3 and No. 4, were raveled down to a specific number of threads (nominal thread count) rather than the 1-inch width specified by ASTM D39.

The samples are not pretensioned but are mounted with sufficient force to remove slack in the specimen between the test jaws.

TONGUE TEAR TESTS

a. ASTM calls for an initial longitudinal cut of 3 inches. In this work the initial slit was 2 ¾ inches.

b. The following data are obtained from the tear diagram.

1. Median upper peak load ($\overline{P}_u$)—obtained by finding the load which has half the upper peaks in 1 inch of tear above it and half below it.
2. Median lower peak load ($\overline{P}_m$)—measured in the same manner as ($\overline{P}_u$).
3. Number of peaks (load drops) per inch of tear.

YARN CRIMP

ASTM calls for 8-inch marks in the fabric, but in this work 10-inch marks were used. The amount of crimp is determined by extrapolating the initial slope of the stress-strain curve to the zero load axis and converting the distance from the origin of the test to this intercept into inches of crosshead motion. The straightened length of the yarn is the sum of this crosshead motion and the original 10-inch gage length.

INSTRON[4] TEST CONDITIONS

	Ravel Strip Tensile	Yarn Crimp	Tongue Tear
Chart Speed (in./min.)	5	5	20
Crosshead Speed (in./min.)	2	2	2
Full-Scale Load	100 lb.	500 gm.	5, 10, & 20 lb.
Gage Length	3-inch	10-inch	3-inch

ABRASION RESISTANCE

The criterion of resistance to abrasion incorporated in this research was the percent loss in tensile strength through abrasion from a rotary platform double head (Taber)[4] abrasion machine (ASTM D1175-55T).

The test conditions were as follows:

Calibrase wheels CS-10[4]
Head load 250 gm.
Resurface wheels 25 cycles for each specimen
Number of cycles = 75% of the number of cycles required to cause a yarn break in the control fabric.

DRAPABILITY

There is no standard method available for measuring the drapability of fabrics that can be considered standard. The test method employed in this work was developed under Contract No. A-1s-31908 and presented to ARS as Progress Reports[5]. The drape coefficient is the projected irregular annular area bounded by the overhanging portion of the draped test fabric and the support disk, expressed as a percentage of the over-all annulus formed by two concentric circles having diameters of 5 inches (supporting disk) and 10 inches (sample size). The data for drape coefficients are the average values of three test specimens. Each 10-inch diameter sample was tested twice, face and back, thus the drape coefficient is the average of six determinations.

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[4] Use of a company and/or product named by the Department does not imply approval or recommendation of the product to the exclusion of others which may also be suitable.

[5] Published by the Agricultural Research Service as ARS 72-17, (1961)

PRESENTATION OF TEST DATA

When a report is concerned with presenting data obtained from 4 groups of experimental fabrics, 31 fabrics in all, the problem arises as to whether it is more helpful to the reader to present the data in many relatively small tables or in a few tables which summarize the results obtained on all of the samples. In this report it has been deemed necessary to do both. Thus, throughout the sections on the discussion of test results the data appropriate to the discussion have been placed in small convenient tables. Whenever it is deemed desirable to see the overall view of the influence of variations in yarn and fabric geometry on the properties studied herein, the reader is directed to the Appendix, which contains six tables of the following descriptions.

Appendix Table	Description of Table
11—	Summary of fabric width, weight, and threads per inch in greige, finished,[6] and resinated fabrics.
12—	Summary of strip tensile strength and rupture elongation of greige, finished,[6] and resinated fabrics.
13—	Summary of tongue tear characteristics of greige, finished,[6] and resinated fabrics.
14—	Summary of nominal and actual relative weights and cover factors in finished[6] and resinated fabrics.
15—	Summary of nominal and actual percent change in relative weights and cover factors in finished[6] and resinated fabrics.
16—	Summary of drape coefficients (% F) of resinated fabrics.

DISCUSSION OF TEST RESULTS

Since this research project is principally concerned with tear strength, the following discussions will deal with tear strength as it is affected by variations in the yarn and fabric structure and as it is affected by the processing treatments between the greige state and the final, resin treated state.

The criterion of resistance to tear is the same as that used in earlier phase reports; namely, the average upper peak load, which may be considered as the theoretical average resistance encountered in tearing through 1 inch of fabric.

During the course of determining the tear strength properties of the experimental fabrics a number of samples were encountered which did not yield any data—by virtue of a gross disproportion in the tear strength of one of their yarn systems relative to that of the orthogonal yarn. The result was tearing of the fabrics in a wrong direction. In order to obtain some qualitative measure of the tear strength of these samples, the tails of the test specimens were folded, producing a V-like slot in the specimen rather than the standard straight-line slit. Such an expedient results in tear strength data lower than the true value; these data are useful, however, in that they permit some measure of relative tear strength. An appropriate notation has been made wherever this procedure has been used.

The principal purpose guiding the design of most of the variations produced for this study was enhancement of yarn mobility in the plane of the fabric. Theoretical considerations on the mechanics of tear and empirical evaluations of the influence of yarn and fabric geometry on tear strength are in accord on this point. The greater the mobility of the two systems of yarn in a fabric structure, the greater the resistance to the propagation of tear through that structure.

Two design features were used rather extensively—separately and in combination—to impart greater mobility to the fabric structure. They involved the use of weaves with long floats, and the specification of lower fabric cover factors. A third feature incorporated reverse twist in the filling direction. This technique was used in a limited (one per warp set) number of samples.

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[6] Without resin.

Another factor which influenced the design of the experimental fabrics was the utilization of coarser yarns for additional tensile strength. These yarns were used in the filling direction, and the number of picks per inch was adjusted to yield either a fairly constant total relative fabric weight or relative filling cover factor. Occasionally these coarser filling yarns were woven with a variety of cover factors and weaves in an attempt to obtain higher tear strength.

TEAR STRENGTH—WARP SERIES NO. 1

Effect on Tear Strength of Variations in Yarn and Fabric Geometry

The control fabric in this series (Sample No. 1) is a duplicate of the printcloth in the series of commercial fabrics examined and reported on in Phase Report No. 1.[7] This type of fabric is widely used in the industry for wash-and-wear prints. It is essentially a 3-oz. per square yard fabric of the 80^2 variety.

Table 1 contains data on tongue tear and other pertinent fabric properties of the control and variation fabrics in the Warp No. 1 series.

Effect of fabric weave.—It is immediately apparent from a cursory examination of the data in Table 1 that the substitution of a 2 x 2 basket weave for a plain weave increases the tear strength of the fabric to a very significant degree. Even more remarkable than the magnitude of the improvement realized over the plain weave control fabric is the fact that the tear strength of all of the warp samples and two out

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[7] See footnote 2.

Table 1.—*Tongue tear and other pertinent fabric properties of the control and variations in the Warp Series No. 1*

FINISHED FABRIC (SANS RESIN)

Sample No.	Control	A[2]	B	C	D	E	F	G	H
Weave[1]	Plain	Plain	Plain	Plain	Basket	Basket	Basket	Basket	Plain
Nominal yarn size (W	30s/1	30s/1	30s/1	30s/1	30s/1	30s/1	30s/1	30s/1	30s/1
(F	40s/1	40s/1	30s/1	30s/1	30s/1	30s/1	40s/1	40s/1	40s/1
Th'ds./in. (W	85	85	85	85	85	84	84	79	82
(F	74	74	66	59	60	69	79	83	80
Yarn crimp (W	4.4	3.9	4.3	4.6	2.6	2.7	1.9	2.4	3.9
(F	13.0	12.1	12.0	12.4	9.4	10.7	10.8	11.2	15.2
Yarn strength (W	.73	.78	.75	.78	.81	.79	.79	.78	.75
(lb./end) (F	.57	.53	.80	.75	.63	.68	.52	.51	.56
Fabric tear str. (W	1.69	1.68	1.68	1.73	4.86	4.05	3.77	3.67	1.62
($\overline{P}_u$) lb. (F	1.27	1.33	1.59	1.59	3.43	3.12	2.84	2.81	1.30
Th'ds./peak[3] (W	1.25	1.31	1.31	1.33	2.22	2.10	2.15	2.14	1.28
(F	1.28	1.23	1.16	1.16	2.31	2.16	2.32	2.30	1.27
RESIN TREATED FABRIC									
Th'ds./in. (W	84	85	84	85	84	85	85	80	81
(F	74	73	65	59	61	69	78	82	80
Yarn strength (W	.45	.45	.44	.45	.52	.54	.54	.53	.46
(lb./end) (F	.31	.30	.44	.41	.33	.34	.24	.24	.31
Fabric tear str. (W	1.40	1.38	1.46	1.56	6.10	4.28	3.83	4.12	1.36
($\overline{P}_u$) lb.[4] (F	.97	1.04	1.21	1.23	3.88	3.45	2.42	2.38	1.04
Th'ds./peak[3] (W	1.50	1.52	1.50	1.54	2.54	2.58	2.50	2.42	1.45
(F	1.42	1.33	1.38	1.37	2.35	2.16	2.29	2.34	1.21
Monsanto crease (W	135°	138°	132°	140°	139°	139°	136°	136°	132°
angle (F	138°	127°	132°	135°	142°	143°	139°	145°	134°

[1] Basket weave is 2 x 2.
[2] Fabric A differs from the control only in the direction of twist in the filling yarns.
[3] Threads/peak represents the average number of del yarns rupturing per peak (load drop) over 1 inch of tear.
[4] Underlining of warp tear data indicates that the tails of the test specimens were folded to prevent tearing in the orthogonal direction.

of four of the filling samples in the resin treated basket weave fabrics exhibited higher values than their nonresinated counterparts despite the tensile losses in the order of 35% in the warp and 50% in the filling. Moreover, the extent of improvement in the warp direction has been limited by the necessity of having to fold the tails of the warpwise tongue tear specimens (thereby decreasing the tear strength of the sample) to prevent the fabric from tearing in the fillingwise direction. Thus one may infer that the resin treatment has reduced yarn to yarn friction, thereby enhancing the mobility of the yarns in the plane of the fabric.

Within the group of four basket weave variations, Sample 1-D exhibited the largest improvement in tear relative to the control fabric, and following the resin treatment it manifested the most significant increase in both warp and filling tear when compared with its nonresinated counterpart. This particular sample embodied the maximum combination of variations; namely, weave, coarse filling yarns, and lower cover factor in both warp and filling.

Effect of cover factor.—In their theoretical outline of the mechanics of tear, Teixeira **et al.**[8] pointed out that tear strength was a function of five parameters of fabric geometry. One of these was the reciprocal of the cover factor. Empirical studies have confirmed that for most textile structures a decrease in the cover factor of the yarns parallel to the direction of tear will result in improved tear strength. In other words, a decrease in the number of filling yarns, other factors remaining relatively constant, will be expected to yield a higher tear strength in the warp direction. Decreasing the cover factor has a twofold effect on the structure of the tear specimen. First, it permits a more desirable (higher) ratio of length to depth of del and, second, it improves the trellising characteristics of the fabric in parallel with the del. Both of these results tend to increase the tear resistance of a fabric.

There are three pairs of experimental fabrics in the Warp No. 1 series which are suitable for evaluating the effect on tear strength of variations in cover factor. Listed below are the pertinent data on relative cover factor and tear strength for these fabrics:

Sample No[1]	Relative cover factor[2]		Tear strength (lb.), $\bar{P}_u$			
			Sans resin		Resinated	
	Warp	Fill.	Warp	Fill.	Warp	Fill.
Control No. 1	15.5	11.7	1.69	1.27	1.40	0.97
1-H	15.0	12.6	1.62	1.30	1.36	1.04
1-B	15.5	12.0	1.68	1.59	1.46	1.21
1-C	15.5	10.8	1.73	1.59	1.56	1.23
1-D	15.5	11.0	4.86	3.43[3]	6.10	3.88
1-E	15.3	12.6	4.05	3.12[3]	4.28	3.45

[1] The yarn size and weaves within each pair are alike.

[2] Relative cover factor = threads/inch divided by $\sqrt{\text{yarn count}}$.

[3] Tails folded.

In the first pair of fabrics (control Sample No. 1 vs. Sample No. 1-H, plain weave, 40/1 filling yarn) the decrease in warpwise relative cover factor in Sample No. 1-H was not as great as had been planned for, and the increase in filling cover factor was larger than anticipated. The result was that the tear strengths of these two samples were found to be equivalent.

The second pair of Samples compared (1-B vs. 1-C, plain weave, 30/1 filling yarn), on the other hand, did have a significant change in fillingwise cover factor, while keeping the warpwise cover factor constant, and as was expected the warp tear strength of Sample 1-C was greater than that of Sample 1-B. The absolute and percent increase in warpwise tear strength was greater in the resin treated state.

Pair number three of samples compared (1-D vs. 1-E) are both 2 x 2 basket weave fabrics, 30/1 filling. In this pair the lowered fillingwise cover factor in Sample 1-D resulted in higher tear resistance in both warp and filling direction. Here again the influence on tear strength of this variation in fabric geometry was more pronounced in the resin treated state than in the finished sans resin condition. Recognizing that resination has reduced the yarn tensile of both fabrics (36% in warp and 50% in filling), and yet that the tear strength of resinated samples exceeds that of the nonresinated sample, one may infer that the resin treatment reduces yarn to yarn friction, thereby enhancing the mobility of the yarns in the plane of the fabric.

Effect of reverse twist in filling yarn.—The use of reverse twist in the filling yarn (S twist in filling, Z twist in warp) was based on the theory that it would minimize nesting of warp and filling yarns at the crossover points, thereby enhancing the mobility of the yarns in the plane of the fabric.

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[8] Teixeira, N. A., Platt, M. M., and Hamburger, W. J. "Mechanics of Elastic Performance of Textile Materials, Part XII: Relation of Certain Geometric Factors to the Tear Strength of Woven Fabrics." Textile Res. Jour. 25: pp. 538-861 (1955).

For this class of fabrics the use of reverse twist in filling yarns did not affect the warpwise tear strength, but it did improve the fillingwise tear by approximately 4% in the unresinated fabric and 7% in the resin treated goods.

Effect of coarser filling yarns and cover factor.—Four of the variations in this set of fabrics utilize coarser (30s/1 vs. 40s/1) yarn in the filling. Two of these are in plain weave, and two are in 2 x 2 basket weaves. Within each weave one fabric was designed to have constant relative total weight[9] (compared with the control fabric) and variable fillingwise cover factor, while the other was designed to have constant cover factor and variable relative total weight.

A summary of the percent increase in tear strength for the four variations which utilized the coarser filling yarns is listed below:

Sample No.	Weave[3]	Change in Total Relative Weight[1]	Change in Relative Filling Cover Factor[2]	Av. Percentage Increase in Tear Strength[4] Sans Resin Warp	Sans Resin Fill	Resinated Warp	Resinated Fill.
1-B	P	Increased	Constant	0	25.2	4.3	24.7
1-C	P	Constant	Decreased	0	25.2	11.4	26.8
1-D	B	Constant	Decreased	188	170	336	300
1-E	B	Increased	Constant	140	146	206	255

[1] Total Relative Weight = warp th'ds. per inch divided by warp yarn size plus picks per inch divided by filling yarn size.

Relative Filling Cover Factor = picks per inch divided by $\sqrt{\text{filling yarn size}}$.

[3] P - Plain Weave; B - 2 x 2 Basket Weave

[4] Compared to Control Fabric.

In this group the 2 x 2 basket weave variation with constant relative total weight and reduced fillingwise cover factor (No. 1-D), effected the largest percent improvement in both warp and filling tear strength. Moreover, both basket weave samples displayed vastly higher percentage increases in tear in the resinated state than in the non-resin-treated state. This may be attributed to the fact that the control fabric exhibited a loss in tear because of resin treatment, whereas the basket weaves manifested an increase in tear strength following the resin treatment.

It is interesting to note that the plain weave variations (Nos. 1-B and 1-C), which utilized coarse filling yarns, exhibited the same percentage improvement in fillingwise tear strength in the finished sans resin fabrics as in the resin treated fabrics. However, their resinated counterparts displayed a distinct superiority in the warpwise tear strength for that structural variation in which the weight was kept constant but the filling cover factor was lowered.

Summary of effect on tear strength of variations in yarn and fabric geometry (Warp Series No.1)—It seemed appropriate, owing to the large body of test results, the number of yarn and fabric variables being considered, and the multiplicity of relationships which exist among the experimental fabrics in the finished sans resin state and in the resin treated state, to give an overall picture of the tear strength properties of this population of experimental fabrics. Accordingly, a summary of all the pertinent tear data is presented in the form of a bar graph (Fig. 1).

The salient points illustrated by this figure are:

1. Using a fancy weave (2 x 2 basket) provided the most effective design feature for improving the level of tear strength.
2. Combining weave with a decrease in cover factor and heavier filling resulted in the highest values of tear resistance in this set of fabrics.
3. Using coarser (stronger) filling yarns in the plain weave samples with either a decrease in filling cover factor (Sample 1-C) or no change in cover factor (Sample 1-B) yielded significant improvements in fillingwise resistance to tear. Of particular interest is the observation that the resin treated tear strength across filling yarns in Samples 1-B and 1-C are equivalent to the fillingwise tear strength of the nonresinated control fabric.
4. Combining coarser filling yarns and lower filling cover factor resulted in a significant increase in the warpwise resistance to tear for Sample 1-C in the resin treated state. To reiterate the assertion made earlier in this report, the observed increase in warpwise tear of the resinated portion of this Sample, as contrasted with the manifest equivalence of warp tear between the control and this variation in the sans resin state, is attributed to a decrease in yarn to yarn friction resulting in greater yarn mobility in the plane of the fabric.

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[9] Relative Weight = Threads per inch/yarn count.

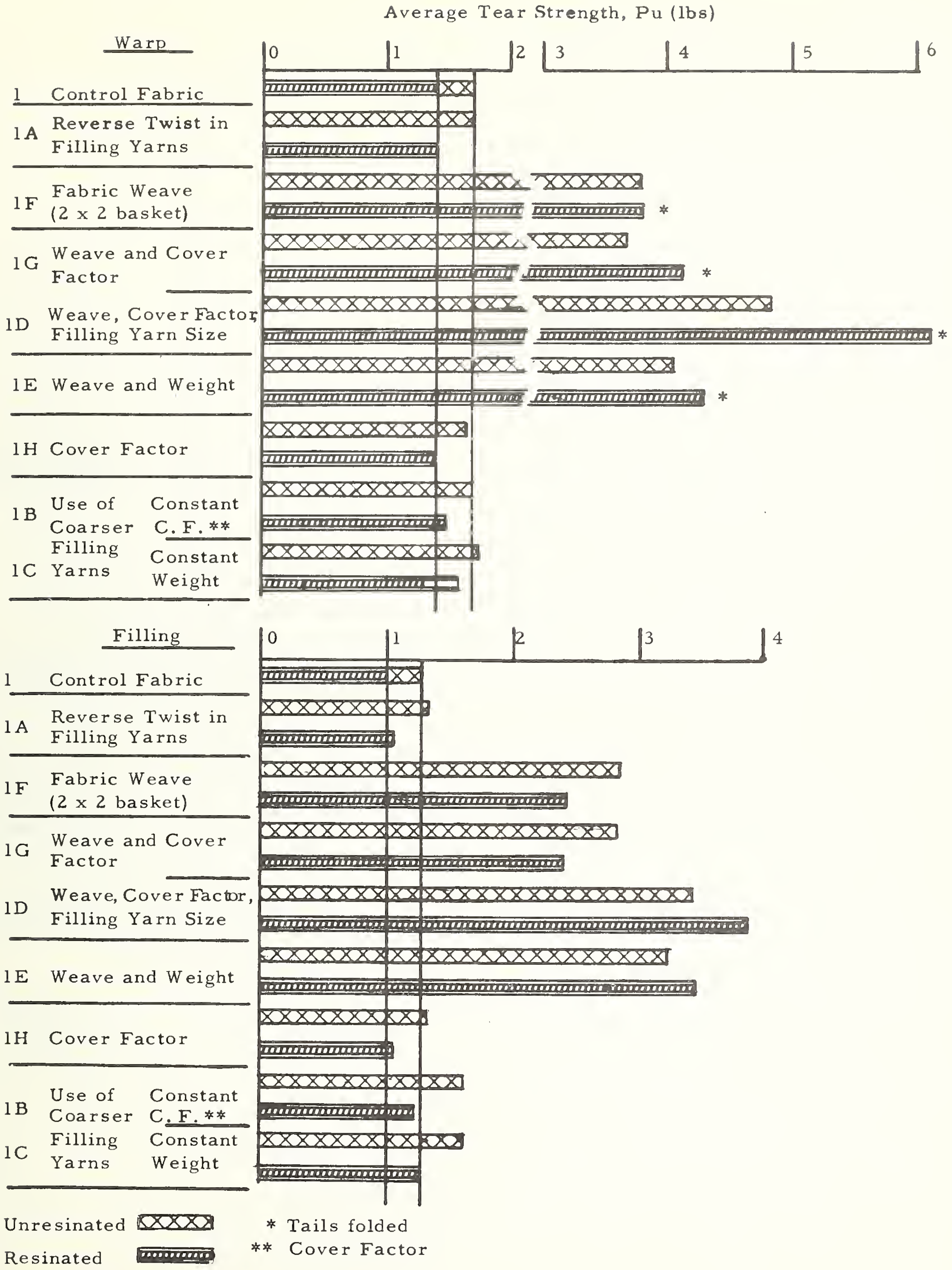


Figure 1.—*Tear strength data for experimental Warp No. 1 series (printcloth).*

Effect of Finishing Processes on Tear Strength of Experimental Fabrics

Before a resin treatment can be applied to a cotton fabric, the fabric must first be subjected to a number of wet finishing treatments (desizing, scouring, and bleaching) in order to "prepare" it for the final step; namely, the resin treatment. It seemed germane to the purposes of this research program to evaluate the effect on tear strength of these preparatory processes with that of the resin treatment.

Since the response to finishing treatments is often a function of fabric weave, the following commentaries involve comparisons among plain weave samples, among fancy weaves (2 x 2 basket weave in this series), and between the plain and fancy weave groups.

Listed below are the average changes in tear strength owing to the preparatory treatments and the resin treatment.

	Av. Absolute Change in Tear Strength (lb.)		Av. Percentage Change in Tear Strength	
	Warp	Fill.	Warp	Fill.
Plain Weave:				
Preparatory Treatments	−2.23	−0.90	−55.8	−38.9
Resin Treatments	− .25	− .32	−14.8	−22.4
2 x 2 Basket Weave:				
Preparatory Treatments	−13.33	−4.24	−77.6	−57.7
Resin Treatments	[1] +0.27	− .02	+11.6	− 1.6

[1] Tails folded.

The above data indicate in rather dramatic fashion that for this series of the fabrics the loss in tear strength resulting from the preparatory finishing treatments is significantly greater than that occasioned by the resin treatment. In fact, the resin treated basket weave samples displayed higher resistance to warpwise tear than their unresinated counterparts.

The studies in phase one of the subject contract indicated that the greatest portion of the loss in tear strength resulting from the preparatory treatments was caused by the scouring operation. Apparently, the removal of the natural lubricants in the cotton increased the yarn-to-yarn friction. Thus yarn mobility was seriously inhibited, with a resultant decrease in resistance to tear forces.

A summary of the percent change in tear strength due to wet finishing treatments is presented in Table 2.

Table 2.—*Summary of percent change in tear strength occasioned by wet finishing treatments (Warp Series No. 1)*

Sample No.	% Change [1] in tear ($\overline{P}_u$)—due to wet finishing treatments			
	Greige vs. Finished [2]		Finished [2] vs. Resinated	
	Warp	Filling	Warp	Filling
Control No. 1	−56.1	−37.1	−17.2	−23.6
A	−44.7	−39.0	−17.8	−21.8
B	−59.0	−38.6	−13.1	−23.9
C	−66.0	−38.6	− 9.8	−22.6
D	[3]	−58.6	[4] +25.5	+13.1
E	−76.6	−62.4	[4] + 5.7	+10.6
F	−77.6	−53.8	[4] + 3.4	−14.8
G	−78.7	−56.2	+12.3	−15.3
H	−53.0	−41.2	−16.0	−20.0

[1] %change based on value of tear strength in the greige goods in the case of greige vs. finished, and on value of finished tear strength in the case of finished vs. resinated.

[2] Finished without resin.

[3] Greige sample could not be torn warpwise even with tails folded.

[4] Warp tongue tear of resin treated samples was performed with tails folded to prevent tearing in the opposite direction. This technique tends, in general, to depress the tear strength of the fabric. Thus, the percentage change for these designated warp samples are underestimated inasmuch as the samples exhibit improved strength.

TEAR STRENGTH—WARP SERIES NO. 2

Effect on Tear Strength of Variations in Yarn and Fabric Geometry

Warp No. 2 series consists of a number of variations of a commercially available broadcloth. The control (Sample No. 2) is a plain weave fabric, approximately 3 oz. per square yard, and 138 x 69 threads per inch in the prepared state. This type of fabric is generally used for shirting material and would probably be given a resin finish of wash-and-wear type whenever a resin treatment is called for.

Tongue tear and other pertinent fabric properties of the control and variations from Warp series No. 2 are listed in Table 3.

Effect of fabric weave.—As in the case of the plain weave printcloth, the tear strength of the broadcloth responds very favorably to a variation in fabric weave. The utilization of oxford or 3/1 twill weaves in place of the plain weave in this construction yielded very satisfactory improvements in tear resistance. The extent of improvement realized in the fillingwise tear of the 3/1 twill was larger than that observed in the oxford in both the resinated and nonresinated samples.

Inasmuch as the 3/1 twill behaves essentially as a twill fabric in the filling direction with respect to distortability by virtue of the positioning of its floats, and the oxford in the filling

Table 3.—*Tongue tear and other pertinent fabric properties of the control and variations in the Warp Series No. 2.*

FINISHED FABRIC (SANS RESIN)

Sample No.		Control	A[1]	B	C	D	E	F
Weave		Plain	Plain	3/1 Twill	Oxford	Plain	Plain	Oxford
Nominal yarn size		48/1-48/1	48/1-48/1	48/1-48/1	48/1-48/1	48/1-40/1	48/1-40/1	48/1-40/1
Th'ds./in.	(W	138	137	137	140	137	137	140
	(F	69	70	71	69	65	61	62
Yarn crimp	(W	8.6	9.1	5.0	3.5	9.9	8.5	5.0
	(F	2.8	2.5	4.6	9.2	2.2	3.5	7.9
Yarn strength	(W	.51	.52	.58	.54	.54	.52	.53
(lbs./end)	(F	.51	.47	.42	.48	.65	.63	.55
Fabric tear strength	(W	1.57	1.50	2.16	2.13	1.60	1.58	2.29
($\overline{P}_u$) lb.	(F	1.04	1.19	1.38	1.18	1.22	1.27	1.35
Threads/peak[2]	(W	1.75	1.63	1.73	2.50	1.78	1.67	2.50
	(F	1.19	1.25	1.36	1.25	1.16	1.13	1.24
RESIN TREATED FABRIC								
Th'ds./in.	(W	138	137	138	139	139	137	138
	(F	69	68	69	68	63	61	61
Yarn strength	(W	.30	.30	.34	.32	.29	.30	.32
(lbs./end)	(F	.31	.30	.24	.27	.38	.35	.32
Fabric tear strength	(W	1.10	1.09	1.42	1.54	1.20	1.20	1.66
($\overline{P}_u$) lb.[3]	(F	.87	1.00	1.06	.99	1.00	1.04	1.18
Th'ds./peak[2]	(W	1.72	1.71	1.68	2.78	1.80	1.67	2.70
	(F	1.33	1.31	1.33	1.33	1.26	1.33	1.30
Monsanto crease	(W	143	141	141	136	145	143	137
angle	(F	130	120	140	133	128	126	129

[1] Fabric A differs from the control only in the direction of twist in the filling yarns.

[2] Threads/peak represents the average number of del yarns rupturing per peak (load drop) during 1 inch of tear.

[3] Fabric A differs from the control only in the direction of twist in the filling yarns. Underlining of warp tear strength data indicates that the tails of the test specimen were folded to prevent tearing in the orthogonal direction.

direction may be considered as a 2 x 2 basket weave with appreciably less ability to distort than the twill, it is not surprising that the filling tear strength of the twill exceeds that of the oxford. Warpwise, the tear strengths of these two weaves may be predicted as equivalent since any advantage the twill may have over the oxford with regard to distortability may be compensated for by the superior elongation balance among the warp yarns in the oxford compared to that of the twill. The test data for the nonresinated Samples supports these observations.

However, the warp tear of the resinated oxford is superior to that of the resinated 3/1 twill. Whether this can be attributable to the difference in test procedure (tails folded in the resinated samples) or to the differences in location of resin resulting from interaction between geometry and the application of resin or to some other cause or combination of causes, was not ascertained; nor could it be ascertained without considerable additional investigation.

The tear strength of the oxford weave was enhanced further by decreasing the fillingwise cover factor slightly and by substituting 40s/1 filling yarn for the 48s/1 used in the control fabric. This triple variation of weave, cover factor, and yarn size (Sample 2-F) resulted in the highest tear strength, in warp or filling direction, observed in any of the resin treated fabrics in this series. In fact, this resin treated experimental fabric exhibited better tear strength, warp and filling, than the control fabric without resin.

Effect of cover factor and coarse filling yarn.—Two pairs of experimental fabrics in this series will permit an evaluation of the effect on tear strength of variations in fabric cover factor combined with use of coarser filling yarns (40s/1 vs. 48s/1). One set is comprised of plain weave fabrics and the other of oxford weave. Listed below are the average tear strength, relative total weight, and relative cover factor for these fabrics in the finished unresinated state:

Sample No.	Weave	Total Relative Weight	Relative Cover Factor		Av. Tear Strength (lb.)	
			Warp	Fill.	Warp	Fill.
Control No. 2	P	4.31	19.9	10.0	1.57	1.04
2-E	P	4.37	19.8	9.6	1.58	1.27
2-C	Ox	4.36	20.2	10.0	2.13	1.18
2-F	Ox	4.47	20.2	9.8	2.29	1.35

It is evident that the combination of coarser filling yarns and decreased filling cover factor have resulted in rather small increases in the total relative weight of Samples 2-E and 2-F. Although in both the oxford and the plain weave pairs there was exhibited improved tear strength in the filling direction as a result of the coarser yarns, in the plain weave samples the decreased filling cover factor did not increase the warpwise tear strength. It is interesting to note that the response of the oxford weave to a lowering of filling cover factor was significant despite the fact that the extent of the decrease was only 2% as opposed to 4% in the plain weave fabric.

The original design of these experimental fabrics had specified a nominal decrease in fillingwise relative cover factor of 9%. However, the experimental fabrics were finished to 61 picks per inch instead of 57. The effect of this combination of variables on the tear resistance of the resin treated portion of these fabrics is evident in the following tabulation of data:

Sample No.	Weave	Av. Tear Strength (lb.)		Total Relative Weight	Relative Cover Factor	
		Warp	Fill.		Warp	Fill.
Control No. 2	P	1.10	0.87	4.31	19.9	10.0
2-E	P	1.20	1.04	4.37	19.8	9.6
2-C	Ox	[1] 1.54	.99	4.31	20.0	9.8
2-F	Ox	[1] 1.66	1.18	4.39	19.9	9.6

[1] Tails folded.

Here also the fillingwise tear strength in both pairs of fabrics and the warpwise tear strength in the oxford were found to have higher tear strength in the samples woven with coarser filling and fewer picks per inch. However, unlike the unresinated fabrics, the warpwise tear in the plain weave has also responded to the variation in filling cover factor.

Effect of reverse twist in filling yarn.—As in the case of the printcloth, the use of "Z" twist in the warp yarns and "S" twist in the filling yarns did not influence the warpwise resistance to tear but it did result in an improvement (14.5%) in filling tear. Samples before and after resin treatment were found to have approximately 14.5% higher tear strength than the control fabric. It appears, therefore, that the fabric geometry of a broadcloth is quite responsive to even "slight enhancement" of yarn mobility when tearing across the filling. This may be due to the relatively large difference between the warp and filling cover factors. It is possible that a highly significant increase in fillingwise tear strength could have been realized through reductions in warp cover factor.

Effect of coarser filling yarns.—It should be quite obvious that it is not possible to change the filling yarn size without concomitantly varying some other fabric geometry parameters such as fabric weight and cover factor. The use of heavier filling yarns in combination with variations in cover factor has already been discussed above. This section demonstrates the effect on tear strength of substituting coarse filling yarns into the broadcloth in such a manner that the relative cover factor was virtually unchanged and the total relative weight was increased only 3.5%. The pertinent data are given below:

Sample No.	Finished	Av. Tear Strength (lb.) Warp	Fill.	Total Relative Weight	Relative Cover Factor Warp	Fill.
Control No. 2	Without Resin	1.57	1.04	4.31	19.9	10.0
2-D	Without Resin	1.60	1.22	4.47	19.8	10.3
Control No. 2	Resinated	1.10	.87	4.31	19.9	10.0
2-D	Resinated	1.20	1.00	4.47	20.0	10.0

It is clear that Sample 2-D has significantly more resistance to tear in the filling direction than the control fabric. This is true in the unresinated as well as the resinated state. There is no change in warpwise tear strength for the pair of fabrics sans resin; however, a definite improvement in warpwise tear is evident in the resin treated sample of experimental fabric No. 2-D. Again, this may be due to lowering of yarn to yarn friction with accompanying enhancement of yarn mobility as a result of resin treatment.

Summary of effect on tear strength of variations in yarn and fabric geometry (Warp Series No. 2).—As in the case of Warp Series No. 1 a summary of the tear data obtained from the Warp Series No. 2 is presented in the form of a graph (Fig. 2).

Of particular interest in this series is the performance of the resin treated fabrics with respect to fillingwise tear. While the control fabric exhibited a 16.3% loss in filling tear following resin treatment, the fillingwise resistance to tear of the resinated experimental fabrics was found, with one exception, to be equivalent to that of the unresinated control fabric. The exception in this case was fabric No. 2-F, which displayed approximately 13.5% higher tear strength than the control fabric finished sans resin. Furthermore, this equivalence in resistance to tear was achieved despite losses in tensile strength averaging about 40%.

Very significant improvements in tear strength were also realized in those variations incorporating weaves with longer floats (3/1 twill) or with two ends weaving as one (oxford). The influence of the weaves was most evident in the warpwise resistance to tear; however, the use of fancy weaves did produce good results in the fillingwise tear as well.

The substitution of slightly coarser filling yarns with concomitant variations in weight and/or cover factor was particularly successful in enhancing the tear strength across the filling yarns. It also effected a 9% increase in the warpwise tear strength of fabrics treated with resin (Samples 2-D and 2-E).

Effect of Finishing Processes on Tear Strength

The average changes in tear strength attributed to preparatory treatments and to application of a resin finish on broadcloth are itemized below:

	Av. Absolute Change in Tear Strength (lb.) Warp	Fill.	Av. Percentage Change in Tear Strength Warp	Fill.
Plain Weave:				
Preparatory Treatments	−1.55	−0.72	−49.7	−38.0
Resin Treatment	−0.42	−0.20	−26.5	−17.1
3/1 Twill & Oxfords:				
Preparatory Treatments	−4.68	−1.16	−68.0	−47.0
Resin Treatment	[1] −0.65	−0.23	−29.5	−17.3

[1] Tails folded.

From this data it appears reasonable to conclude that the losses in tear strength resulting from the preparatory treatments are of far greater magnitude, both in the absolute and relative sense, than the losses attributed to resin treatment. Additionally, the twills and oxfords appear to have suffered higher losses in tear strength resulting from preparatory treatments than the plain weave Samples. However, losses in tear strength attributable to the resin treatment are of similar average percentage for all three weaves.

Table 4 contains a summary of the changes in tear occasioned by the preparatory finishing and resin treatments.

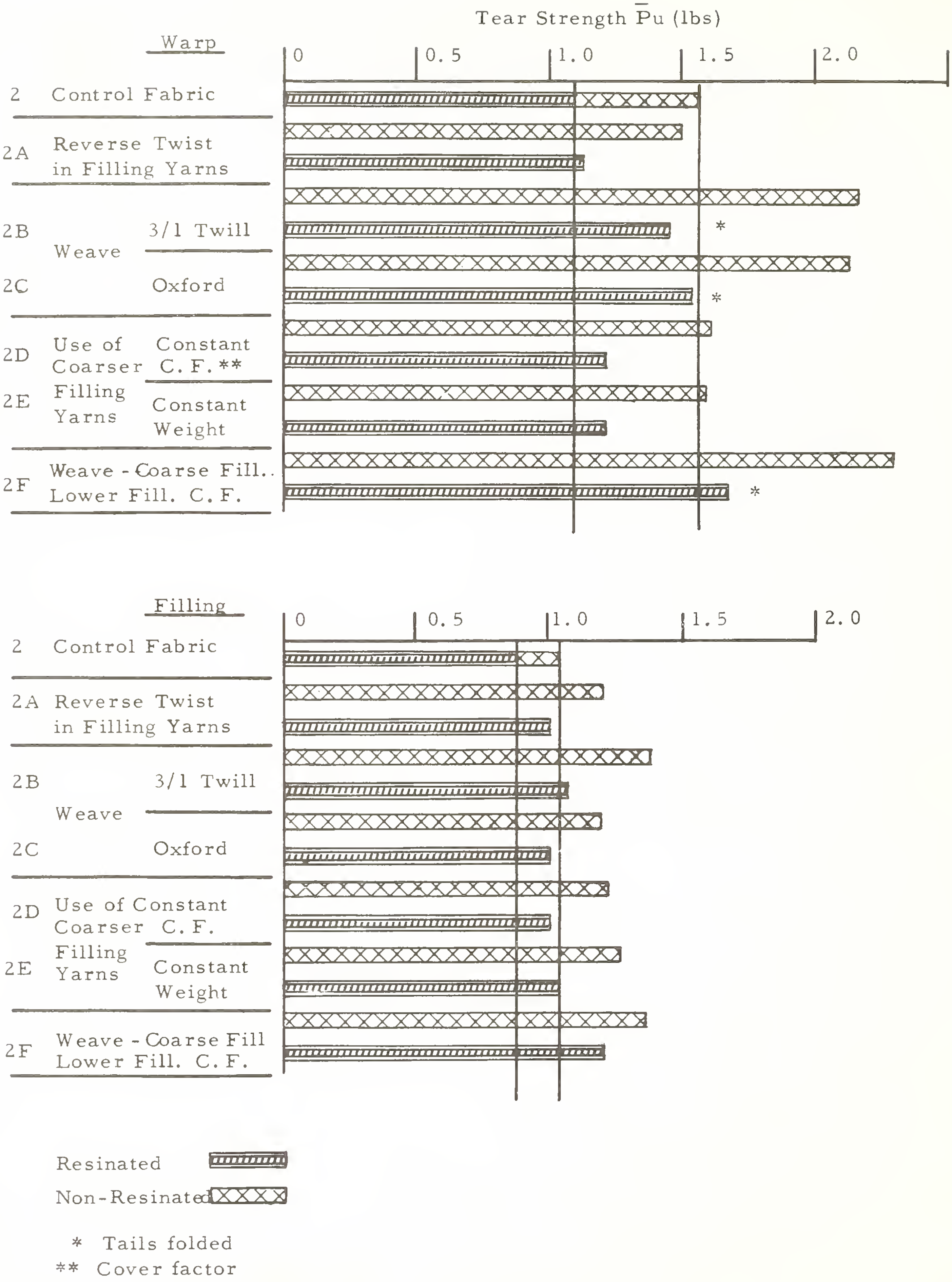


Figure 2.—*Summary of tear strength data for experimental Warp No. 2 series (broadcloth).*

Table 4.—*Summary of percent change in tear strength occasioned by wet finishing treatments (Warp Series No. 2)*

Sample No.	% Change [1] in tear ($\overline{P}_u$)—due to wet finishing treatments			
	Greige vs. finished [2]		Finished [2] vs. resinated	
	Warp	Filling	Warp	Filling
Control No. 2	−47.5	−41.2	−29.9	−16.3
A	−50.8	−38.0	−27.3	−16.0
B	−65.2	−47.3	[3] −33.3	−23.2
C	−69.8	−46.8	[3] −27.7	−16.1
D	−49.0	−37.8	−25.0	−18.0
E	−51.7	−35.2	−24.0	−18.1
F	−69.0	−46.8	[3] −27.5	−12.6

[1] % Change based on value of tear strength in the greige goods in the case of greige vs. finished, and on value of finished tear strength in the case of finished vs. resinated.

[2] Finished without resin.

[3] Warp tongue tear of resin treated samples was performed with tails folded to prevent tearing in the opposite direction. This technique tends, in general, to depress the tear strength of the fabric. Thus the percentage change for these designated warp Samples are exaggerated inasmuch as the Samples manifest losses in tear.

Effect on Tear Strength of Variations in Yarn and Fabric Geometry

The third series of experimental fabrics designed and produced for this research program is composed of cotton fabrics in the sateen work clothing weight class. The control fabric (Sample No. 3) is a 5-harness sateen, 132 x 57 threads per inch in the prepared state, with a finished fabric weight of 6.7 oz. per square yard.

Table 5 contains the tongue tear data along with data of pertinent yarn and fabric parameters for this series of fabrics.

Effect of fabric weave.—The nature of a sateen weave is such that it may be considered as having very few contiguous alternating

Table 5.—*Tongue tear and other pertinent fabric properties of the control and variations in the Warp Series No. 3.*

FINISHED FABRIC (SANS RESIN)

Sample No.		Control	A [1]	B	C	D	E
Weave		Sateen	Sateen	Oxford	Sateen	Sateen	Oxford
Nominal yarn size		22/1-15/1	— — — — — — — — Same as control fabric — — — — — — — —				
Finished fabric (sans resin)							
Threads/inch	(W	132	131	130	126	126	125
	(F	57	56	54	58	50	47
Yarn crimp	(W	7.4	6.9	13.5	7.0	5.8	11.3
	(F	7.6	6.4	8.4	7.4	7.2	7.0
Yarn strength	(W	1.04	1.06	.87	1.01	1.07	.86
(lb./end)	(F	1.46	1.38	1.59	1.43	1.42	1.55
Fabric tear strength							
($\overline{P}_u$) lb.	(W	5.43	5.38	5.28	5.16	5.76	5.15
	(F	5.68	4.90	3.82	5.37	5.79	3.55
Threads/peak [2]	(W	1.61	1.54	2.76	1.58	1.62	2.60
	(F	1.24	1.25	1.29	1.32	1.28	1.09
RESIN TREATED FABRIC							
Threads/inch	(W	130	130	131	126	125	125
	(F	55	55	52	57	50	47
Yarn strength	(W	.75	.75	.62	.78	.78	.61
(lb./end)	(F	.96	.91	1.25	.98	.93	1.10
Fabric tear strength							
($\overline{P}_u$) lb.	(W	5.03	------------	3.42	5.05	6.12	------------
	(F	4.38	3.75	2.82	4.42	4.41	2.75
Threads/peak [2]	(W	1.86	------------	2.38	1.88	1.95	------------
	(F	1.41	1.25	1.44	1.46	1.35	1.42
Monsanto	(W	108	115	116	111	117	121
crease angle	(F	143	135	117	142	145	123

[1] Fabric A differs from the control only in the direction of twist in the filling yarns.

[2] Threads/peak represents the average number of del yarns rupturing per peak (load drop) during 1 inch of tear.

intersections per weave repeat. Consequently, it is considered an excellent weave type when resistance to tear is an important consideration in the performance requirement of a fabric.

No attempt was made to improve the tear strength of the sateen fabric by substitution of another weave, e.g., a basket weave, because this would have meant the adaptation of a weave traditionally alien to the work clothing class of fabrics. Accordingly, it seemed appropriate to demonstrate the excellence of the sateen weave by comparing it with an oxford. Furthermore, inasmuch as Warp Series No. 4 contained 3/1 twill fabrics, also in the work clothing category, one of the Sample variations in this series could be used for purposes of comparison. The sample best suited for comparison with Samples 3 and 3-B by virtue of the similarity in cover factors and weight, was variation 4-D. Listed below are the pertinent data on these three weaves:

Sample	Weave	Total Relative Weight	Relative Cover Factor		Tear Strength (lb.), ($\overline{P}_u$)			
					Sans Resin		Resinated	
			Warp	Fill.	Warp	Fill.	Warp	Fill.
Control No. 3	Sateen	9.80	28.1	14.7	5.43	5.68	5.03	4.38
3-B	Oxford	9.51	27.7	13.9	5.28	3.82	3.42	2.82
4-D	3/1 Twill	10.93	29.4	12.9	6.30	4.57	[1] 4.33	2.83

[1] Tails folded.

All samples were produced with 15/1 filling yarn. Warp Series No. 3 has 22/1 in the warp, and warp No. 4 15/1. The difference in levels of tear strength in the warp direction between the two samples from warp No. 3 and that of the 3/1 twill from warp No. 4, may be ascribed to the difference in tensile strengths of the warp yarns. Such reasoning may not be applied to the variety of tear strength levels displayed by the fillingwise tear results. The diversity of resistance to tear in the filling direction is almost entirely a result of variations in weave for Samples 3 and 3-B and primarily so for Sample 4-D.

An additional point in favor of the sateen weave is brought out by the following tabulated comparison of the changes in tear strength due to resin treatment:

Sample No.	Weave	Av. Percent Loss in Tear Strength		Crease Angle
		Warp	Fill.	Warp and Fill.
Control No. 3	Sateen	7.4	22.9	251°
3-B	Oxford	35.2	26.2	233°
4-D	3/1 Twill	31.3	38.1	238°

It is quite evident that the sateen weave suffered the lowest percentage decrease in warp tear as a result of resin treatment, despite the fact that it displayed significantly higher total crease angle than either the oxford or the 3/1 twill.

Effect of cover factor.—Because it was recognized that sateen weaves perform satisfactorily when subjected to the stresses and deformations of a tearing action, a pair of sateens varying only in cover factor and weight were produced as part of No. 3 series. A comparison of the control with these two variations is presented below.

Sample No.	Total [1] Relative Weight	Relative [1] Cover Factor		Tear Strength (lb.), $\overline{P}_u$			
				Sans Resin		Resinated	
		Warp	Fill.	Warp	Fill.	Warp	Fill.
Control No. 3	9.80	28.1	14.7	5.43	5.68	5.03	4.38
3-C	9.60	26.9	15.0	5.16	5.37	5.05	4.42
3-D	9.06	26.9	12.9	5.76	5.79	6.12	4.41

[1] Values were obtained from the finished unresinated samples; the relationship among these samples in the resin treated state is ostensibly the same.

Variations 3-C and 3-D both have lower relative weights than the control. Sample 3-C has lower warp cover factor but the same filling cover factor; Sample 3-D was produced with lower cover factors in both warp and filling.

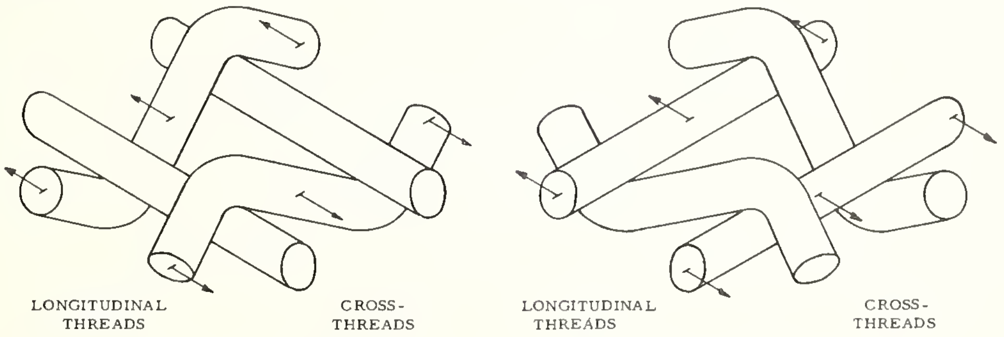
The resultant changes in the tear strength of experimental fabric 3-C are somewhat disappointing. However, for Sample 3-D the changes are quite encouraging in the case of the unresinated fabric, and are considered outstanding when the fabric was resin treated. The warpwise tear of the resinated portion of Sample 3-D exceeded that of its unresinated counterpart and of the non-resin-treated control fabric to a highly significant degree.

At first glance, then, one would be tempted to conclude that for unresinated Samples 3-C and 3-D a variation in warp cover factor alone is insufficient and that it is necessary to vary both cover factors to achieve any desirable results. While it is certainly quite evident that the unresinated Sample 3-D is superior to the unresinated 3-C, when the Samples are resinated there is something to be said for Sample 3-C. The loss in warpwise tear strength due to resin treatment in Sample 3-C was 2.1% in the warp and 17.7% in the filling, compared with the respective losses of 7.4% and 22.9% for the control fabric. Sample 3-D, on the other hand, gained 6% tear strength in the warp and lost about 23% in the filling yarns.

Another interesting relationship among these three fabrics which may provide additional insight as to why their tear strengths have been affected by variations in cover factor may be found in a consideration of their warp and filling crimps, tabulated as follows:

Sample No.	Percent Crimp Warp	Percent Crimp Fill.
Control No. 3	7.4	7.6
3-C	7.0	7.4
3-D	5.8	7.2

Sample 3-D possesses the most favorable distribution of yarn crimps insofar as resistance to the propagation of warpwise tear strength is concerned. While there is not as yet a scientific basis for quantitative predictions of the effect of crimp magnitude and its distribution on tear strength, certain extreme cases can be cited which indicate what one may reasonably expect. For example, consider a tear across the warp yarn system, the filling yarn being the longitudinal ones. The longitudinal thread cover factor will determine the limit of thread sliding prior to jamming. Additionally, for a warp crimp close to zero (high filling crimp), it is clear that resistance to sliding will be very low, i.e., the highly crimped filling yarns will encounter little resistance in sliding over the almost straight warp, and therefore a relatively large del will be formed upon the application of a low external force, resulting in a relatively high tear strength. For this type of fabric, tearing across the highly crimped filling will evoke relatively higher resistance to fabric distortion, since the low crimp warp would not easily slide across the high crimp filling; thus a relatively low tear strength will result. The situation is illustrated in Figure 3 for the two cases cited.



LOW CRIMP IN CROSS THREADS
LOW RESTRAINT TO LONGITUDINAL
THREAD SLIDING

A

HIGH CRIMP IN CROSS THREADS
HIGH RESTRAINT TO LONGITUDINAL
THREAD SLIDING

B

Figure 3.—A, *Low crimp in cross threads, low restraint to longitudinal thread sliding;* B, *high crimp in cross threads, high restraint to longitudinal thread sliding.*

Effect of reverse twist in filling yarns.—In this series of experimental fabrics the use of yarns with opposite twist in warp and filling, designed to minimize the ill effects of nesting, resulted in significant losses in fillingwise tear. There is no clear explanation for this reversal in the relative performance expected of these experimental fabrics; to list the possible variants and interactions which might have brought about the observed results would not clarify the problem. Suffice it to say that the tear tests have been replicated and the replications have confirmed the original findings. Thus it can be stated with confidence that the samples were not inadvertently reversed.

Summary of effect on tear strength of variations in yarn and fabric geometry (Warp Series No. 3).—Figure 4 summarizes, for all of the experimental fabrics in this series, the average upper peak loads, $\overline{P}_u$, the expression of resistance to tear throughout this work. As for the previous graphs, test data for the nonresinated and resinated samples are included.

There are three noteworthy considerations concerning Figure 4. First, it is quite apparent that Sample 3-D is the outstanding experimental fabric in this series. It has displayed the highest level of tear strength in warp and filling. But of even greater significance is

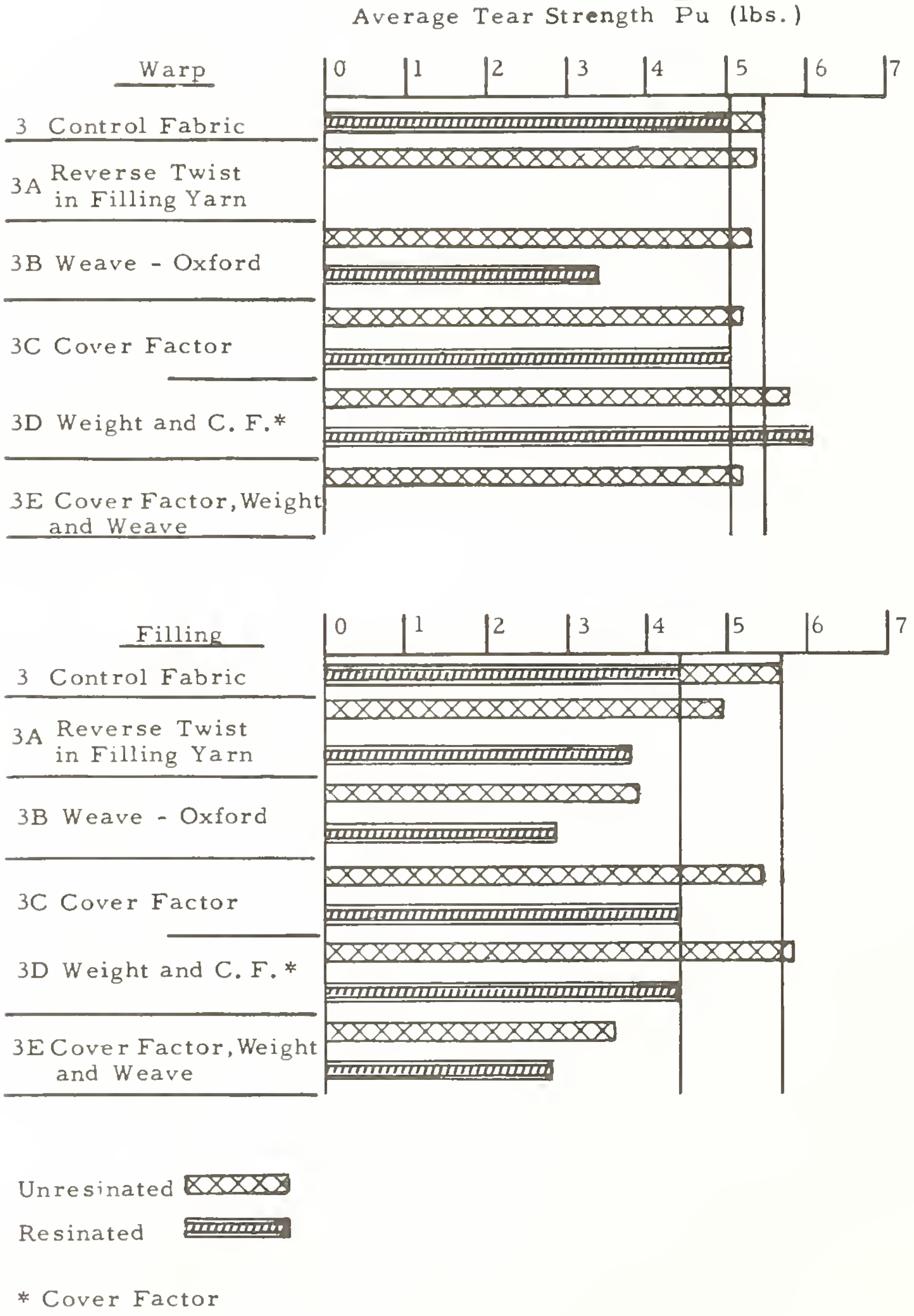


Figure 4.—*Summary of tear strength data for experimental Warp No. 3 series (sateen work clothing).*

the evidence that its warpwise tear resistance is greater following resin treatment than before.

The second important point is concerned with the control fabric. In each of the other warp series in this research program it has been generally true that the tear strengths of the experimental fabrics have exceeded that of the control fabric. In this series, with one exception, the control fabric has demonstrated an equivalence or distinct superiority to the experimental variations with respect to resistance to tear.

The third point is the failure (with one exception) of the experimental fabrics displaying higher tear strength in the non-resin-treated state than the control fabrics to maintain this superiority in the resinated state. The single exception was Sample 3-D (discussed above).

Effect of Finishing Processes on Tear Strength

Listed below are the average changes in tear strength observed on this series of fabrics following the preparatory treatments (desizing, scouring, and bleaching) and following the application of resin:

	Av. Absolute Change in Tear Strength (lb.)		Av. Percentage Change in Tear Strength	
	Warp	Fill.	Warp	Fill.
Sateen Weave:				
Preparatory Treatments	−5.40	−2.40	−49.7	−30.5
Resin Treatment	−0.16	−1.20	− 3.1	−21.9
Oxford Weave:				
Preparatory Treatments	−1.61	+0.07	−23.4	+ 2.1
Resin Treatment	−1.86	−0.90	−35.2	−24.3

Several interesting relationships are evident in the data. For example, the effect of preparatory treatments on tear resistance of sateen is markedly greater than it is on the tear resistance of oxford samples. Fillingwise, the oxfords displayed virtually no change in resistance to tearing, from the greige to the prepared state. This suggests that the oxford greige goods may have been near the jammed state in the warp direction and that the subsequent loss of lubricity occasioned by the preparatory treatments did not affect the mobility of the filling yarns in the oxford fabrics; hence, the equivalence in fillingwise tear in the oxfords between the greige goods and the prepared fabrics. On the other hand, the loss of lubricity, and consequently of mobility, in the warp of the oxfords was evident in the 23.4% loss in tear strength resulting from preparatory treatments, suggesting that the oxford goods may not have been jammed in the filling direction.

The sateens, being inherently readily distortable fabrics, would be expected to suffer significant losses in tear strength following any change in mobility of yarns. Thus it is not particularly surprising to find the loss in tear strength from the preparatory treatments to be approximately 50% warpwise but only 30% fillingwise.

The effects of resin treatment on the tear characteristics of the sateen and oxford fabrics are somewhat more complex. An examination of percentage changes in warpwise tear resistance for the sateen fabrics clearly indicates that this property has not been affected by resin treatment. The oxford fabrics, on the other hand, have displayed a loss in warpwise tear of approximately 35 percent. As to filling tear resistance, there was little difference percentagewise between the tear strength effect of resination on the sateen and on the oxford fabrics, the effect on the sateens being almost as great as that on the oxfords.

This latter point is difficult to rationalize. The diversity of behavior manifested by the sateen and oxford samples in resistance to warpwise tear may be ascribed to the obvious difference in their fabric distortability and yarn mobility characteristics, but this same difference should exist in the filling direction. There is no clear-cut, simple answer to the disparity exhibited by the sateen samples in their warpwise and fillingwise tear strength reactions following resin treatment. Such factors as crimp balance, cover factor, and yarn size undoubtedly played a part in determining the extent of the altered tear performance of the fabric. However, there is insufficient data available for any reliable assessment of the relative contributions each of these factors made in determining the observed tear characteristics.

An additional point which should be brought out is the fact that for the oxford weaves the percent loss in tear attributed to resin-treating the fabric is greater than the percent loss resulting from the preparatory treatments. This is the first instance of such a relationship being observed.

The details of the percentage change in tear strength of the experimental fabrics due to the wet finishing treatments are presented in Table 6.

TEAR STRENGTH—WARP SERIES NO. 4

Effect on Tear Strength of Variations in Yarn and Fabric Geometry

Warp No. 4 series is a set of variations of a twill work clothing fabric. The control fabric is a 3/1 twill, 117 x 55 threads per inch in the prepared state, with a finished fabric weight of approximately 8 oz. per square yard.

The average test results for tear strength and other pertinent yarn and fabric properties are listed in Table 7. It will be noted that the

Table 6—*Summary of percent change in tear strength occasioned by wet finishing treatments (warp series No. 3)*

Sample No.	Weave	% Change [1] in tear ($\overline{P}_u$—due to wet finishing treatments Greige vs. finished [2] Warp	 Greige vs. finished [2] Filling	 Finished [2] vs. resinated Warp	 Finished [2] vs. resinated Filling
Control No. 3	Sateen	—48.3	—32.4	— 7.4	—22.9
A	Sateen	—46.6	—35.3	----------	—23.4
B	Oxford	—18.6	+ 8.2	—35.2	—26.2
C	Sateen	—55.2	—31.9	— 2.1	—17.7
D	Sateen	—48.8	—22.4	+ 6.2	—23.8
E	Oxford	—28.2	— 4.0	----------	—22.5

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[1] % change based on value of tear strength in the greige goods in the case of greige vs. finished, and on value of finished tear strength in the case of finished vs. resinated.

[2] Finished without resin.

Table 7.—*Tongue tear and other pertinent fabric properties of the control and variations in the Warp Series No. 4*

FINISHED FABRIC (SANS RESIN)

			Variations							
Sample No.		Control	A [1]	B	C	D	E	F	5	(5B)
Weave		3/1 Twill	3/1 Twill	Oxford	3/1 Twill	3/1 Twill	Oxford	Oxford	3/1 Twill	Oxford
Nominal yarn size	(W	15/1	15/1	15/1	15/1	15/1	15/1	15/1	14/1	14/1
	(F	15/1	15/1	15/1	15/1	15/1	15/1	15/1	15/1	15/1
Th'ds./in	(W	117	118	119	115	114	114	114	104	106
	(F	55	55	55	56	50	55	49	56	56
Yarn crimp	(W	10.5	10.2	12.5	9.6	8.1	11.2	10.6	9.9	9.1
	(F	8.3	9.3	13.0	10.0	9.2	13.3	12.6	10.3	15.8
Yarn strength	(W	1.32	1.37	1.23	1.34	1.37	1.17	1.40	1.60	1.62
lb./end)	(F	1.47	1.51	1.55	1.46	1.28	1.71	1.67	1.62	1.79
Fabric tear str.	(W	5.82	5.86	6.35	.93	6.30	6.81	6.80	7.25	7.44
($\overline{P}_u$) lb.	(F	4.43	5.38	3.92	4.76	4.57	4.03	4.16	5.29	4.74
Th'ds./peak [2]	(W	1.58	1.57	2.34	1.58	1.54	2.54	2.28	1.71	2.65
	(F	1.22	1.20	1.28	1.22	1.19	1.34	1.36	1.30	1.40
RESIN TREATED FABRIC										
Th'ds./inch	(W	117	117	119	113	113	114	114	103	105
	(F	54	55	53	54	48	54	48	53	55
Yarn strength	(W	.98	.99	.90	.99	1.04	.86	.97	1.18	1.19
(lb./end)	(W	.99	1.05	1.15	.96	.90	1.26	1.10	1.00	1.37
Fab. tear str.	(W [3]	4.20	4.26	4.09	4.09	4.33	4.16	4.36	4.33	4.29
($\overline{P}_u$) lb.	(F	3.14	3.51	2.36	3.16	2.83	2.76	2.41	3.26	3.03
Th'ds./peak [2]	(W	1.46	1.50	2.02	1.47	1.47	2.28	2.11	1.34	1.91
	(F	1.32	1.28	1.13	1.28	1.30	1.42	1.37	1.43	1.31
Monsanto crease	(W	128	132	106	128	125	110	110	124	107
angle	(F	110	106	111	110	112	116	116	107	108

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[1] Fabric A differs from the control only in the direction of twist in the filling yarns.

[2] Threads/peak represents the average number of del yarns rupturing per peak (load drop) during 1 inch of tear.

All warp tear tests on resin treated Samples were performed with specimen tails folded to prevent tearing in opposite direction.

warpwise tear strength of the resinated goods was obtained by utilizing the procedure of folding the tails to induce tear in the warp direction. For this class of fabrics the data obtained in this manner may perhaps be insensitive to variation of fabric geometry, and thus the true differences which exist between the fabric Samples may be obscured. These warp data are included in the ensuing discussions as points of interest, but the reader is cautioned that the data probably represent less than the actual tear resistance of these resinated goods, unlike the data for filling tear, which are actual values obtained through legitimate techniques.

Effect of fabric weave.—It has just been demonstrated, that a nonresinated sateen weave, even one of lighter weight, will manifest a significant improvement in fillingwise tear strength when compared to a 3/1 twill sans resin fabric. Moreover, in the resin treated state the sateen exhibits considerably higher tear strength than the resinated 3/1 twill in both warp and filling direction.

In this series of fabrics, one variation (Sample 4-B) is similar to the control fabric in all yarn and fabric parameters. It differs from the control only in its weave, an oxford. The average tear strength (upper peak load) for the two weaves is tabulated as follows:

		Average tear strength (lb.)			
		Without Resin		Resinated	
Sample	Weave	Warp	Fill.	Warp	Fill.
4	3/1 Twill	5.82	4.43	[1]4.20	3.14
4-B	Oxford	6.35	3.92	[1]4.07	2.36

[1] Test specimen tails folded.

As one would anticipate, the nonresinated samples of oxford weave exhibited significantly higher warpwise tear strength than such samples of the 3/1 twill. Yet, this improvement in warpwise tear was accompanied by a loss in fillingwise tear. In the resin treated state, the superiority in warpwise tear of the oxford is no longer in evidence. It may be that the device of folding the tails to induce tear in the warp direction was responsible for the shift in ranking of the twill and oxford. Fillingwise, there is little reason to doubt the evidence that the oxford weave suffered considerably more loss in tear than the twill fabric.

For this weight and texture class of goods, it would appear reasonable to rank the sateen weave as the most desirable, with respect to resistance to tear forces; the 3/1 twill would be considered the second best and the oxford ranked as the lowest.

Effect of cover factor.—In evaluating the magnitude of the change in tear strength resulting from variations in cover factor, it seemed desirable to present the data in the form of the percent change in tear associated with the percent change in weight and cover factor. All percentages are based on the value of the control fabric. Accordingly, the pertinent data for the three experimental fabrics which varied from the control only with respect to cover factor are listed below in terms of percent change in fabric properties:

The percentage change in total relative weight observed in experimental fabric No. 4-C, and the change in relative cover factor as well, are considered insignificant; as one would expect, they did not produce any significant changes in tear strength. This was part of the risk inherent in the original design of the experimental fabric. At the time the fabrics were designed it was agreed that changes in their geometry were to be kept within a reasonable limit. Thus, the majority of variations were designed to result in changes in the order of 5, 10, and 15%. Fabric No. 4-C was supposed to have a 5% reduction in warp cover factor.

	Percentage Change[1] in—		
Sample No.	Relative Total Weight	Cover Factor	
		Warp	Fill.
4-C	—0.7	— 1.6	+1.4
4-D	—4.7	— 2.6	—9.2
5	—2.7	—21.2	+1.4

Percentage Change[1] in Tear Strength			
Sans Resin		Resinated	
Warp	Fill.	Warp	Fill.
0	+ 7.4	—2.6	0
+ 8.2	+ 3.2	—3.1	—10.5
+24.6	+19.4	—3.1	+ 3.8

[1] All percentages calculated as follows:

$$\%\text{Change in data} = \frac{\text{Control Fabric Data} - \text{Expt. Fabric Data}}{\text{Control Fabric Data}} \times 100$$

In this instance the inability to control the variables of weaving and finishing to a greater degree resulted in a poor Sample.

Sample 4-D was designed to have a reduced filling cover factor of 9.1% and it actually finished at -9.2%. However, the actual reduction in warp cover factor was half of what was desired. Here again, the inability to obtain the required fabric dimensions more precisely lessened the tear strength results. While the warp tear strength of the sans resin fabrics increased by 8.2%, the increase in filling tear was negligible. The resin treatment completely negated whatever advantage was evidenced by the nonresinated experimental goods.

The last Sample of the group, No. 5, is not, strictly speaking, a variation in cover factor alone. The warp yarns are 14/1 as opposed to 15/1 in the control fabric. This change in yarn size was not considered significant enough to warrant presentation of No. 5 data in a separate section. Thus the Sample is included in this group of cover factor variations. The data for No. 5 clearly indicate that a substantial improvement in tear strength has been achieved by the yarn and fabric variations present in this Sample. While the magnitude of the percentage increase in warpwise tear strength exceeds that of the fillingwise tear, it is probably a less significant improvement than the increase in filling tear. This observation is prompted by the fact that the percentage increase in warp tear is equivalent to the percentage increase in warp yarn tensile strength, whereas the 19.4% improvement in fillingwise tear came about with no change in filling yarn strength. The change in resistance to fillingwise tear, therefore, can be attributed almost entirely to the 21.2% reduction in relative warp cover factor.

Despite the significant increase in the tear strength of the No. 5 sans resin fabrics discussed above, the application of the resin treatment resulted in a complete cancellation of any advantage of the experimental over the control fabric. This was the case with weave variations, discussed in the preceding section, and it is generally true for all of the experimental fabrics in this fourth series. There appears to be a strong interaction between the resin treatment and the experimental fabrics, which nullifies the superiority of these fabrics over the control in the sans resin state. This situation is quite contrary to the experience reported earlier herein on the other fabrics, which in many instances manifested higher percentage improvements in tear strength in the resinated fabrics than in the nonresinated fabrics.

Effect of weave and cover factor.—Within this twill series of fabrics there were three variations combining a change in weave with a reduction in cover factor. The pertinent data are listed as follows:

Sample No.	Percentage Change[1] in— Total Relative Weight	Percentage Change[1] in— Cover Factor		Percentage Change[1] in Tear Strength Sans Resin		Percentage Change[1] in Tear Strength Resinated	
		Warp	Fill.	Warp	Fill.	Warp	Fill.
4-E[2]	—1.7	— 2.6	------------	+17.0	—9.0	0	—12.1
4-F[2]	—5.2	— 2.6	—11.3	+16.8	—6.1	+3.8	—23.2
5-B[2]	—1.5	—19.9	+ 1.4	+27.8	+7.0	0	— 3.5

[1] Based on control fabric.

[2] Oxford weaves.

Basically, the only difference between these data concerning the combination of weave and cover factor effect and the like data of the preceding section on cover factor effect alone is that the degree of improvement in the warp tear strength is higher and the effect on the fillingwise tear strength is lower. As before, the resin treated experimental samples did not retain their relative superiority over the control fabric.

For these oxford weave Samples it is possible to measure in two ways the percent change in tear strength of the experimental fabrics, one based on the 3/1 twill control fabric and the second based on an oxford weave, Sample 4-B, comparable in construction with the control. The former represents the combinations weave and cover factor, with which this section is concerned, and the latter is a measure of the effect of reduced cover factor alone. The warp and filling percentage changes in tear strength of three oxford Samples as based on the control are compared with the percent changes as based on the oxford 4-B, as follows for non-resin-treated and resinated samples:

Non-Resin-Treated Fabrics (Oxford Weave)

Comparison of Percentage Change[1] in Tear Strength of—

Sample No.	Warp		Filling	
	Control	4-B	Control	4-B
4-E	+17.0	+ 7.2	−9.0	+ 2.8
4-F	+16.8	+ 7.1	−6.1	+ 6.1
5-B	+27.8	+17.2	+7.0	+20.9

[1] Percent changes in tear strength of both warp and filling yarns are based on the value for the control fabric and on that for Sample 4-B.

The percentage increases in warp tear based on the control fabric are greater than those based on the oxford weave, Sample 4-B. However, the relationship is reversed in the case of the changes in fillingwise tear resistance.

In the resin treated state there exists little difference between the percent change in warp tear based on the control and that based on the oxford Sample 4-B. Fillingwise, however, there is a considerable difference between the results obtained from these two bases of calculating percent change in tear strength.

Resin-Treated Fabrics (Oxford Weave)

Comparison of Percentage Change[1] in Tear Strength of—

Sample No.	Warp		Filling	
	Control	4-B	Control	4-B
4-E	0	0	−12.1	+16.9
4-F	+3.8	+6.6	−23.2	+ 2.1
5-B	0	+4.9	− 3.5	+28.3

[1] Percent changes in tear strength of both warp and filling yarns are based on the value for the control fabric and on that for Sample 4-B.

The data based on the 3/1 twill control fabric indicate a superiority in the filling tear resistance of this control over the experimental oxfords. The data based on the control oxford fabric indicate that the reduced cover factors have yielded significantly higher levels of tear strength in the experimental oxfords. Thus, within the 3/1 twill series, reductions in cover factor did not yield the anticipated effect on tear strength, whereas within the oxford series they did.

Another point of interest is brought out by a comparison of the effect on tear strength of the interaction between reduced cover factor and weave (3/1 twill versus oxford). Listed as follows are the changes in tear strength associated with these two weaves for three reductions in cover factor as shown by three comparisons of samples:

Samples		Non-Resin-Treated Fabrics % Change[1] in Tear Strength				Resin-Treated Fabrics % Change[1] in Tear Strength			
		Warp		Filling		Warp		Filling	
Twill	Ox	Twill	Ox	Twill	Ox	Twill	Ox	Twill	Ox
4-C	4-E[2]	0	+ 7.2	+ 7.4	+ 2.8	—2.6	0	0	+16.9
4-D	4-F[3]	+ 8.2	+ 7.1	+ 3.2	+ 6.1	—3.1	+6.6	—10.5	+ 2.1
5	5-B[4]	+24.6	+17.2	+19.4	+20.9	—3.1	+4.9	+ 3.8	+28.3

[1] Changes in tear strength of 3/1 twills and oxfords are based on the value for the twill control fabric and on that for the oxford Sample 4-B.

[2] Reduced warp cover factor approx. 3%.

[3] Reduced filling cover factor approx. 10%.

[4] Reduced warp cover factor approx. 22%.

There are several interesting points evident in these data. It is immediately apparent that the resin treated twills do not respond as favorably to reductions in cover factor as do the oxford fabrics. This point is even more significant when one considers that in the nonresinated state the improvements in tear strength of the 3/1 twill, occasioned by these reductions in cover factor, were generally similar to those of the oxford samples. Another point brought out by this analysis is the relatively high response of the oxford sample in the resinated state to even slight decreases in warp cover factor. Note that the 16.9% increase in fillingwise tear strength for oxford Sample 4-E was associated with approximately 3% reduction in warp cover factor. This Sample in its unresinated state did not exhibit any real improvement in tear over oxford Sample 4-B. Thus, it would appear that certain variations in fabric structure require the assistance of the finishing treatment to yield the desired results.

Effect of reverse twist in filling yarns.—The expedient of reversing the direction of twist in the filling yarns (Sample 4-A) resulted in a considerable increase (21.4%) in filling tear strength. Moreover, the resin treatment, while it did minimize the effect of reverse twist on tear strength, did not eradicate its influence, so an 11.8% higher filling tear was observed in the resinated experimental fabric. Although it must be admitted that the magnitude of improvement is not very large, in light of the failure of any other variation to produce a significant increase in tear resistance in the resinated state, this increase of approximately 12% assumes added importance.

Summary of effect on tear strength of variations in yarn and fabric geometry (Warp Series No. 4).—Figure 5 contains a summary of the average upper peak loads (tear strength) for all of the experimental fabrics in this series. The warpwise tear strength for the resin treated samples is not included in this bar graph, since all of the tests were performed with folded tails and it is believed that for this weight class of fabrics this artifice obscures the existing relationship of tear strength. Moreover, the extent to which the apparent tear strengths of the variations fluctuated above and below that of the control was considered negligible.

Perhaps the most important finding to come out of the tear strength studies of this series of fabrics is the poor showing of the variation samples following resin treatment. In all but one case, any improvement manifested in filling tear strength in the non-resin-treated state by means of a variation in geometry was virtually wiped out in the resinated state. In the single instance (reverse twist in filling yarn) in which any significant enhancement in fillingwise tear was carried over into the resinated state, the extent of the increase was reduced to nearly half of that observed in the sans resin fabrics.

The reason the loss in tear strength of the resinated twill fabrics is considered important is the fact that already it had been found that the sateen work clothing samples also exhibited this undesirable behavior; the lightweight fabrics (printcloths and broadcloths) on the other hand, generally had an equivalence in the percentage change in tear (variation vs. control) for both the sans resin and resin treated samples and quite often the percentage increase thus determined was greater in the resinated variations than in the non-resin-finished goods. An explanation of this diversity in the response of the light and heavyweight goods to resin treatment could comprise a rather extensive study in itself, and is beyond the scope of the present work.

Another point of interest stemming from the work on this warp series is the interaction between weave, reduced cover factor, and resin treatment. Here it was found that lowering the cover factor of the nonresinated 3/1 twill and oxford weaves resulted in certain increases in tear strength dependent on the degree of reduction in cover factor. The improvement determined for the 3/1 twills was based on the tear strength of the control fabric, and that for the oxford weaves was based on the tear strength of Sample 4-B, an oxford weave equivalent in construction to the control fabric. When these fabrics were resin treated, the 3/1 twills of reduced cover factor, which before resination had displayed higher values of tear than the control, exhibited comparable or lower levels of tear strength. The oxfords, on the other hand, continued to display higher levels of tear in those resin treated samples which had reduced cover factors.

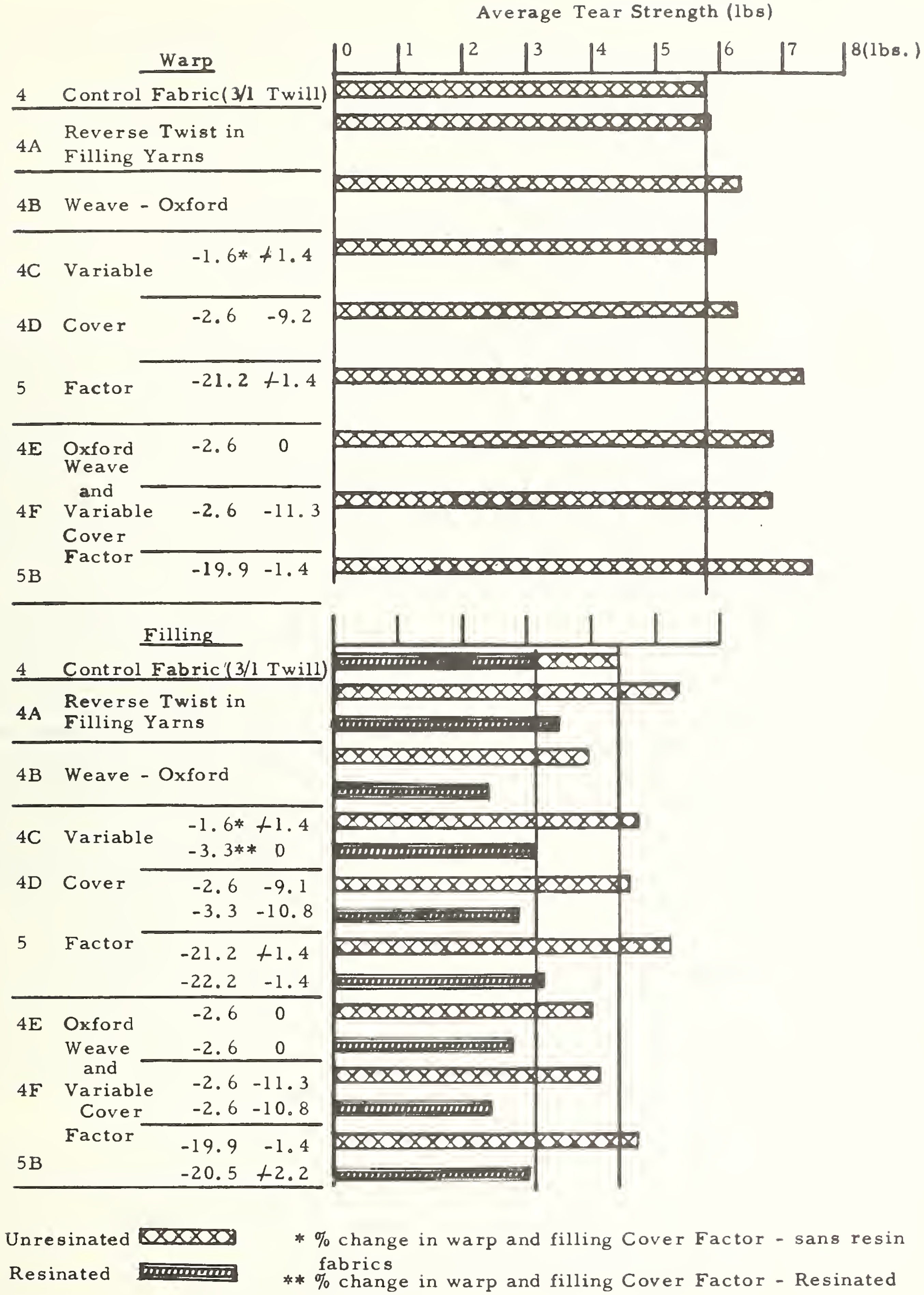
The single variation which evidenced higher tear strength (fillingwise) than the control in the resinated state was Sample 4-A, which utilized reverse twist in the filling yarns.

Effect of Finishing Processes on Tear Strength of Experimental Fabrics

The average changes in tear strength occasioned by the preparatory treatments (desizing, scouring, and bleaching) and by the application of a resin treatment on this fourth set of experimental fabrics are listed as follows:

	Av. Absolute Change in Tear Strength (lb.)		Av. Percentage Change in Tear Strength	
	Warp	Fill.	Warp	Fill.
3/1 Twill:				
Preparatory Treatments	−3.77	0.85	−37.6	−14.9
Resin Treatment	[1] −1.93	1.71	−30.5	−34.8
Oxford Weave:				
Preparatory Treatment	−2.10	+0.38	−23.4	+ 9.8
Resin Treatment	[1] −2.62	−1.57	−38.2	−37.4

[1] Tails folded.



* % change in warp and filling Cover Factor - sans resin fabrics

** % change in warp and filling Cover Factor - Resinated fabrics

Figure 5.—*Summary of tear strength data for experimental Warp No. 4 Series (work clothing twill).*

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Of the fabrics examined in this phase of the subject contract, this is the only warp series in which the percent loss in tear strength attributable to the action of the resin treatment is comparable to or in excess of the losses sustained as a result of the preparatory treatments. In fact, the only other example of such a relationship is that of the oxford weave in warp series No. 3.

The details of the percentage change in tear strength of the experimental fabrics due to the wet finishing treatments are presented in Table 8.

Table 8.—*Summary of percent change in tear strength occasioned by wet finishing treatments (Warp Series No. 4)*

Sample No.	% Change[1] in tear ($\overline{P}_u$)—due to wet finishing treatments			
	Greige vs. finished[2]		Finished[2] vs. resinated	
	Warp	Filling	Warp	Filling
Control No. 4	−38.6	−20.2	[3] −27.8	−29.1
A	−41.0	−12.8	[3] −27.3	−34.8
B	−24.5	+ 7.1	[3] −35.6	−39.8
C	−37.1	−13.4	[3] −25.2	−33.6
D	−42.6	−18.5	[3] −31.3	−38.1
E	−23.6	+ 8.9	[3] −38.9	−31.5
F	−26.4	+12.1	[3] −35.9	−42.1
No. 5	−28.8	− 9.9	[3] −40.3	−38.4
5B	−19.3	+11.3	[3] −42.3	−36.1

[1] % Change based on value of tear strength in the greige goods in the case of greige vs. finished, and on value of finished tear strength in the case of finished vs. resinated.

[2] Finished without resin.

[3] Warp tongue tear of resin treated samples was performed with tails folded to prevent tearing in the opposite direction. This technique tends, in general, to depress the tear strength of the fabric. Thus the percentage change for these designated warp Samples are exaggerated inasmuch as the Samples manifest losses in tear.

Tear Strength of Certain Resin Treated Experimental Fabrics Compared to Tear Strength of Unresinated Control Fabrics

Up to this point, the report has been largely concerned with the relationship between the tear strength of the control fabric and that of the variation or experimental fabric at the same stage of finishing. However, an important aim of this research program is finding how to produce a fabric which in the resin-treated state has equivalent or better resistance to tear than it possessed in the non-resin-treated state. There are two distinct approaches to this, one dealing with the chemistry of the problem and the other with the physics or mechanics of the problem. The present research is concerned with the mechanics. Obviously, there is also a third approach; namely, a combination of the first two.

It is gratifying to report that several variations in a particular three of the four warp series studied herein exhibited levels of tear strength in the resin finished samples comparable or superior to those of the nonresinated control fabric. More than 60% of these samples (there are 13 samples in all) exhibited this very desirable relationship in both warp and filling direction. These 13 samples represent approximately half of the experimental fabrics produced for study in this (fifth) phase of the subject contract.

The details of the tear strength and other pertinent properties of the resinated variations which were found comparable or superior to the nonresinated control in resistance to tear are listed in Table 9. It is interesting to note that in every case in which both the warp tear and the filling tear of the resin treated variations are shown as equal to or greater than those of the nonresinated control, the fabric weave had been changed from a plain weave to a fancy weave. "Fancy" is used in the sense that the weave incorporates longer floats but is nevertheless one of the standard weaves.

The use of coarser filling yarns in combination with either a weave variation or change in cover factor also yielded excellent results. In one case (2-A) the adoption of reverse twist in the filling yarns produced a level of fillingwise tear strength in the resin finished fabric equal to that of the control fabric sans resin. The two examples of this sort of relationship in the heavyweight fabrics were both from the warp No. 3 sateen work-clothing series. In these samples only the warpwise tear of the resinated fabric was comparable to the non-resin-treated control. Sample 3-D, which had significantly reduced cover factor in warp and filling, displayed appreciably higher warpwise tear strength in the resin finished sample than its nonresinated control.

Evaluation of Other Fabric Properties of Certain Resinated Experimental Fabrics Which Displayed Improved Tear Strength

The foregoing discussions have been limited generally to the analysis of tear strength as it is affected by variations in yarn and fabric geometry. It would be naive to imagine that structural changes constitute a factor influenc-

Table 9.—*Tear strength and other pertinent fabric properties of resinated experimental fabrics which exhibited tear resistance comparable or equivalent to that of the nonresinated control fabric.*

Sample No.	Weave	Total relative weight	Relative cover factor		Filling yarn size	Av. tear strength (lb.)	
			Warp	Filling		Warp	Filling
Control No. 1 [1]	Plain	4.68	15.5	11.7	40/1	1.69	1.27
1C	Plain	4.80	15.5	10.8	30/1	1.56	1.23
1D	2x2 Basket	4.83	15.3	11.1	30/1	[2] 6.10	3.88
1E	2x2 Basket	5.13	15.5	12.6	30/1	[2] 4.28	3.45
1F	2x2 Basket	4.78	15.5	12.3	40/1	[2] 3.83	2.42
1G	2x2 Basket	4.72	14.6	12.9	40/1	[2] 4.12	2.38
Control No. 2 [1]	Plain	4.31	19.9	10.0	48/1	1.57	1.04
2A	Plain	4.27	19.8	9.8	48/1	--------	1.00
2B	3/1 Twill	4.31	19.9	10.0	48/1	[2] 1.44	1.06
2C	Oxford	4.31	20.0	9.8	48/1	[2] 1.54	.99
2D	Plain	4.47	20.0	10.0	40/1	--------	1.00
2E	Plain	4.37	19.8	9.6	40/1	--------	1.04
2F	Oxford	4.39	19.9	9.6	40/1	[2] 1.66	1.18
Control No. 3 [1]	Sateen	9.80	28.1	14.7	15/1	5.43	5.68
3C	Sateen	9.53	26.9	14.7	15/1	5.05	--------
3D	Sateen	9.01	26.6	12.9	15/1	6.12	--------

[1] All data obtained from resin treated samples except for the control fabrics.

[2] Tails folded.

ing only the ability of a fabric to resist the propagation of a tear. Clearly, other fabric properties are also affected, and this section of the report describes the observed effects of these geometric variations on such properties as tensile strength, abrasion resistance, drapability, and crease recovery. Table 10 contains a summary of these fabric properties for certain of the resinated experimental fabrics which exhibited significant improvements in tear strength in the resin finished state.

An examination of the data in Table 10 will reveal a very important point; namely, that the samples with improved tear strength did not suffer any adverse side effects in such performance characteristics as drape, crease recovery, and tensile strength. In fact, some of the variations displayed improvements in these properties as well as in tear strength. Note the enhanced drape in Samples 1-D and 4-A, and the appreciable increase in warpwise crease recovery manifested by Sample 3-D.

Table 10.—*Summary of fabric properties of selected resinated fabrics which displayed improved tear strength.*

Sample No.	Weave	% change [1] in tear strength		Abrasion resistance			Drape coeff. (% F)	Monsanto crease recovery		Ravel strip tensile (lb.)	
		Warp	Fill.	No. of [2] cycles	% Loss in tensile Warp	Fill.		Warp	Fill.	Warp	Fill.
Control No. 1	Plain	----------	----------	244	20	50	58.3	135°	138°	38	23
1C	Plain	+ 11	# 27	244	19	54	59.3	140°	135°	38	24
1D	2 x 2 Basket	+336	+300	244	30	61	53.8	139°	142°	44	20
Control No. 2	Plain	----------	----------	229	50	0	60.6	143°	130°	41	21
2E	Plain	+ 9	+ 20	229	66	6	60.5	143°	126°	41	22
2F	Oxford	+ 51	+ 36	229	7	58	58.6	137°	129°	45	19
Control No. 3	Sateen	----------	----------	338	10	0	65.0	108°	143°	98	53
3D	Sateen	+ 22	0	338	20	0	65.6	117°	145°	98	47
Control No. 4	3/1 Twill	----------	----------	1125	0	0	76.5	128°	110°	115	54
4A	3/1 Twill	0	+ 12	1125	17	1	70.6	132°	106°	116	58

[1] Based on tear strength of control fabric.

[2] No. of cycles represents 75 percent of average number of cycles necessary to produce a hole.

The effect of these yarn and fabric variations on the abrasion resistance, as reflected by the percent loss in tensile strength, was considered moderate in all but two cases. One of these, Sample 2-F, exhibited a very significant increase in percent loss in filling tensile (from 0 to 58%); however, it also displayed a considerable diminution in percent loss in warp tensile (from 50 to 7%). Its abrasion resistance, therefore, is essentially the same as that of the control fabric, except that the direction of the poorest abrasion resistance has shifted from the warp to the filling. The other case in which the change in abrasion characteristics was considered excessive was Sample 4-A. For this fabric the warpwise abrasion resistance varied from essentially zero loss in tensile for the control fabric to 17% loss for the experimental fabric. Since these two fabrics, control Sample No. 4 and Sample 4-A, differed from each other only in the direction of twist in the filling yarns, it is very difficult to explain the change in warpwise abrasion resistance on the basis of structural changes in the fabric. Whether nesting or lack of nesting at the yarn crossover points could bring about such a change in abrasion resistance cannot be resolved from the present data.

Based on the data presented in Table 10 it appears reasonable to conclude that in most cases a variation in fabric structure producing significant improvement in tear strength does not produce significantly adverse concomitant changes in other important fabric properties. Moreover, in certain cases the structural variation produced improvements in other fabric properties such as drape and crease recovery.

SUMMARY OF FINDINGS

The two areas of primary interest in the subject contract (Parts III and IV) are reported herein. The first area (A) concerns changes in tear strength resulting from the finishing treatments for any particular geometric pattern. The second area (B) concerns evaluation of the influence on tear strength of variations in yarn and fabric geometry of: (1) Fabrics finished without resin, and (2) resin treated fabrics. This second area of study dealing with the influence of structural variations on tear strength involves three aspects; namely:

a. Comparison of the tear strengths of resin treated fabrics and their unresinated counterparts.
b. Comparison of the tear strengths of resin treated fabrics and their resinated controls.
c. Comparison of the tear strengths of resin treated fabrics and their unresinated controls.

The following observations in line with the above paragraph, are generalized statements of the important points brought out by the studies, concerning: (A) Finishing, and (B) geometry.

A. Changes in Tear Strength of Cotton Fabrics Occasioned by "Preparatory" Finishing Treatments and by the Application of Resin Treatment

In general, both the preparatory finishing treatments (desizing, scouring, and bleaching) and the resin treatment cause a decrease in the tear resistance of cotton fabrics.

The magnitude of the loss in tear strength from the greige to the "prepared" state for the printcloth, broadcloth, and sateen fabrics is generally far greater than the loss between the "prepared" and resin treated states. The greatest losses in tear strength during the preparatory finishing treatments were associated with the operations of scouring.

"Fancy" weave fabrics (standard weaves with longer floats) are more adversely affected by the preparatory finishing treatments than are the plain weave fabrics, although the tear strengths of the fancy weaves exceed those of the plain weaves at all stages of finishing.

The warp tear strengths are more adversely affected by the preparatory finishing treatments than are the filling tear strengths.

B. (1). *Effect on Tear Strength of Variations in Yarn and Fabric Geometry in Finished Cotton Fabric Sans Resin*

In broad terms the analysis of the test data confirmed the hypothesis that improvements in tear strength will generally result from two types of variation in fabric structure; namely, variations which enhance the distortability of the fabric structure and those which result in stronger yarns. The former type of variation was achieved individually by the use of weaves with longer floats, by decreases in cover factor, or by employing a direction of twist in one system of yarns opposite to that of the orthogonal yarns, thereby reducing the potential nesting at the yarn crossover points. The latter type of variation has been found effective when the strengthening of the yarns is obtained by use of coarse yarns with concomitant changes in the fabric structure so as to avoid adversely affecting the relative cover factor of the sample.

The four basic constructions examined in this work (printcloth, broadcloth, sateen, and twill) exhibited a variety of responses to the type of variations employed. In the majority of cases the percentage improvement in tear strength realized in the printcloth and broadcloth was significantly higher than the improvement in the sateen and twill work clothing. However, it should be understood that it is easier to improve the tear resistance of a plain weave fabric than that of a sateen or twill.

In most cases a combination of two or more variations in a single fabric produced greater improvements in tear resistance than was produced when the variations were incorporated individually.

The greatest improvements in tear resistance were occasioned by the utilization of fancy weaves in place of plain weaves. However, substantial improvements were also realized in those variations which substituted stronger yarns, and in the fabrics with reduced cover factor.

B. (2). *Effect on Tear Strength of Variations in Yarn and Fabric Geometry in Resin Treated Fabrics*

a. Comparison of the Tear Strengths of Resin Treated Fabrics and their Unresinated Counterparts

With few exceptions the percent loss in tear strength of the variations was comparable to the loss exhibited by the control fabric. The most notable exceptions were the four variations in the printcloth series which utilized the 2 x 2 basket weave. These samples displayed higher tear strength (up to 25%) in the resin treated state than they did in the "prepared" state.

Another variation in the printcloth series which utilized a combination of coarser filling and lower filling cover factor manifested negligible loss in tear strength following resin application. Two variations in the sateen series utilizing slightly reduced warp and filling cover factors also exhibited little change in tear strength resulting from the resin treatment. Thus, some evidence exists to indicate an interaction between type of fabric geometry and resin treatment.

b. Comparison of the Tear Strengths of Resin Treated Fabrics and Their Resinated Controls

The hint of an interaction between fabric geometry and resin treatment alluded to above is made manifest by a comparison of the relationships between resin treated controls and the variation samples, with the relationships between nonresinated controls and their variations. These relationships for the resinated fabrics would have remained unchanged in comparison with the relationships in the nonresinated fabrics if no interaction existed. However, there were many alterations for the resinated fabrics in the magnitude of the percentagewise difference in tear strength between control and variation. Half the changes in the control-to-variation relationship in the resinated state were improvements, while the remainder were considered undesirable changes. In addition, 75% of the adverse changes were observed in a single construction; namely, the twill work clothing.

The variations in yarn and fabric geometry were generally more effective (percentagewise) in improving the tear strength of the printcloth and broadcloth, in the resin treated state, than for the sateen and twill.

The series of sateen work clothing displayed both adverse and enhanced response to the influence of the variations in the resin treated fabrics. With one exception, the series of twill work clothing did not respond satisfactorily to the influence of structural variations in the resin treated state. Sample 4-A, which contained reverse twist in the filling, was the exception.

c. Comparison of the Tear Strengths of Resinated Variations and their Unresinated Controls

Perhaps the most dramatic result emanating from this research is the demonstration that it is possible, by varying yarn and fabric geometry, to maintain the same level of tear strength (and in some cases to raise it) in the resin treated cotton fabric as was present in the nonresinated control fabric, despite losses in yarn tensile strength in the order of 30 to 50%.

All of the fancy weave variations in the resinated printcloth series exhibited significantly higher tear strengths than the nonresinated control. Use of a more open weave and stronger filling yarns resulted in an equivalence in tear strength between the resinated variation and nonresinated control.

This was true of the broadcloth series in all of the variations relative to the fillingwise tear strength and in half of the variations relative to the warpwise tear strength.

In the sateen work-clothing series, a slight reduction of warpwise and fillingwise cover factors in the resinated variations brought about an equivalence in warpwise tear strength with the nonresinated control. Moreover, while the observed fillingwise tear strength was significantly lower than that of the control, the two variations displayed the highest level of fillingwise tear strength of the series.

APPENDIX

Table 11.—*Summary of fabric constructions of greige and resinated USDA experimental fabrics*

Sample No.	Fabric width (inches)			Fabric weight (oz./sq. yd.)			Threads per inch		
	Greige	Finished[1]	Resinated	Greige	Finished[1]	Resinated	Greige	Finished[1]	Resinated
Control No. 1	39.8	36.7	37.4	3.70	3.26	3.27	80 x 77	85 x 74	84 x 74
A	40.0	36.8	37.4	3.70	3.20	3.27	80 x 77	85 x 74	85 x 73
B	39.8	36.5	37.5	3.88	3.47	3.48	79 x 67	85 x 66	84 x 65
C	40.0	37.1	37.4	3.67	3.28	3.38	80 x 60	85 x 59	85 x 59
D	40.2	37.4	37.5	3.52	3.24	3.33	80 x 60	85 x 60	84 x 61
E	40.4	37.5	37.6	3.78	3.45	3.52	79 x 69	84 x 69	85 x 69
F	40.0	37.6	37.6	3.54	3.20	3.29	79 x 78	84 x 79	85 x 78
G	39.9	37.8	37.7	3.47	3.21	3.23	76 x 81	79 x 83	80 x 82
H	40.0	36.7	37.3	3.66	3.28	3.30	76 x 83	82 x 80	81 x 80
Control No. 2	39.9	39.1	39.3	3.42	2.93	2.98	136 x 70	138 x 69	138 x 69
A	40.0	39.3	39.4	3.40	2.94	3.01	136 x 68	137 x 70	137 x 68
B	40.2	38.9	39.2	3.29	2.90	2.90	136 x 68	137 x 71	138 x 69
C	40.0	38.4	38.9	3.33	2.93	2.95	134 x 69	140 x 69	139 x 68
D	40.0	39.4	39.4	3.48	3.05	3.09	135 x 64	137 x 65	139 x 63
E	40.0	39.3	39.4	3.49	3.00	3.01	134 x 61	137 x 61	137 x 61
F	40.0	38.6	39.0	3.39	2.98	2.99	135 x 61	140 x 62	138 x 61
Control No. 3	39.8	38.0	38.5	7.58	6.68	6.67	127 x 56	132 x 57	130 x 55
A	39.8	38.4	38.7	7.51	6.63	6.61	126 x 56	131 x 56	130 x 55
B	40.0	38.4	38.4	7.90	6.71	6.80	124 x 57	130 x 54	131 x 52
C	39.8	38.4	38.3	7.54	6.62	6.58	122 x 59	126 x 58	126 x 57
D	39.8	38.4	38.7	7.10	6.23	6.21	122 x 52	126 x 50	125 x 50
E	40.0	38.5	38.5	7.49	6.23	6.16	120 x 50	125 x 47	125 x 47
Control No. 4	39.0	36.9	37.2	9.23	8.11	7.98	110 x 59	117 x 55	117 x 54
A	39.0	36.6	36.9	9.27	8.08	7.99	110 x 59	118 x 55	117 x 55
B	40.0	37.2	37.4	9.02	8.27	8.11	110 x 56	119 x 55	119 x 53
C	40.0	37.1	37.4	9.03	7.94	7.77	106 x 59	115 x 56	113 x 54
D	40.1	37.2	37.5	8.64	7.49	7.48	105 x 52	114 x 50	113 x 48
E	39.8	36.6	36.9	8.92	8.01	8.04	105 x 59	114 x 55	114 x 54
F	39.9	36.7	36.9	8.59	7.65	7.56	105 x 52	114 x 49	114 x 48
5	40.0	36.9	37.2	8.79	7.74	7.54	95 x 58	104 x 56	103 x 53
5B	39.9	36.4	36.8	8.78	7.96	7.78	95 x 60	106 x 56	105 x 55

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[1] Without resin.

Table 12.—*Summary of strip tensile strength and rupture elongation of greige, finished,*[1] *and resinated USDA experimental fabrics*

Sample No.	Weave[2]	Ravel strip tensile strength (lb.)						Rupture elongation (%)					
		Greige		Finished[1]		Resinated		Greige		Finished[1]		Resinated	
		Warp	Fill.	Warp	Fill.	Warp	Fill.	Warp	Fill.	Warp	Fill.	Warp	Fill.
Control No. 1	P	60.9	42.9	61.9	42.0	37.6	23.2	18.8	16.2	12.2	22.0	7.9	16.0
A	P	58.9	43.3	66.4	39.4	38.5	21.9	18.6	15.9	12.3	22.1	7.9	16.0
B	P	59.4	50.7	63.7	52.6	37.2	28.3	16.5	16.4	12.5	24.1	8.1	17.4
C	P	60.2	41.5	66.6	44.4	38.4	24.0	14.3	15.5	11.9	21.7	7.5	16.5
D	B	63.5	34.7	68.8	37.7	43.7	20.2	10.1	13.2	10.8	17.5	6.5	13.3
E	B	64.0	41.8	66.6	46.9	49.8	23.2	10.7	14.6	10.5	20.1	6.4	15.5
F	B	63.7	35.3	66.3	41.2	45.9	18.9	10.7	14.2	10.0	20.8	6.3	15.1
G	B	56.8	37.4	62.0	42.5	42.3	19.8	9.2	14.2	10.7	20.0	5.8	14.8
H	P	56.1	44.8	61.9	44.6	37.5	25.1	17.5	16.5	12.1	24.6	7.3	17.4
Control No. 2	P	69.0	32.0	70.8	39.0	41.5	21.2	20.4	10.2	15.4	10.7	10.2	7.3
A	P	71.6	30.6	71.9	33.0	41.2	20.7	18.6	10.0	16.7	10.2	9.8	7.2
B	T	76.0	26.1	78.8	29.8	46.9	16.5	12.0	11.2	12.7	12.2	7.7	8.2
C	O	69.9	31.6	75.0	33.0	44.9	18.4	12.3	15.1	12.0	17.3	7.0	11.7
D	P	72.4	34.1	73.9	42.0	40.1	24.3	15.3	10.0	17.5	10.1	10.0	7.1
E	P	74.0	32.6	71.9	38.6	41.0	21.6	19.8	9.8	16.2	10.5	9.7	7.0
F	O	72.7	31.7	74.8	33.9	44.7	19.3	13.3	14.6	12.5	16.4	7.1	11.9
Control No. 3	S	138	80	138	83	98	53	16.5	14.1	15.3	16.3	9.4	11.2
A	S	139	78	139	77	98	50	15.1	13.1	14.3	15.1	9.1	10.2
B	O	117	97	113	86	81	65	28.3	12.6	19.4	16.3	12.5	13.7
C	S	136	80	137	83	99	56	17.3	12.8	13.8	16.1	9.1	11.6
D	S	141	69	135	71	98	47	14.9	12.2	13.5	15.7	8.9	10.5
E	O	113	84	107	73	77	52	29.4	11.7	17.8	14.5	11.0	11.6
Control No. 4	T	160	82	155	81	115	54	30.9	11.4	18.0	16.5	12.4	12.6
A	T	155	81	162	83	116	58	30.1	11.4	17.6	17.3	12.2	13.4
B	O	144	92	147	85	108	61	27.0	12.8	20.1	20.3	15.2	17.7
C	T	126	80	154	82	112	52	29.6	11.6	17.2	19.1	12.0	15.3
D	T	149	73	156	64	118	43	25.7	10.5	16.6	18.4	11.1	14.8
E	O	134	106	134	94	98	68	30.5	12.6	19.2	23.0	15.5	19.7
F	O	143	92	160	82	111	53	28.4	12.0	19.0	21.2	13.7	19.0
5	T	158	95	167	91	122	53	30.6	11.1	19.6	20.2	12.1	16.7
5B	O	156	116	172	100	125	75	28.4	13.7	18.7	25.6	15.3	23.9

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[1] Without resin.

[2] Weaves: P, Plain; B, 2 x 2 Basket; T, 3/1 Twill; O, Oxford; S, Sateen.

Table 13.—*Summary of tongue tear characteristics of greige, finished,*[1] *and resinated USDA experimental fabrics*

Sample No.	Weave[1]	Average upper peak load (lb.)						Threads rupturing per peak					
		Greige		Finished[1]		Resinated		Greige		Finished[2]		Resinated	
		Warp	Fill.	Warp	Fill.	Warp	Fill.	Warp	Fill.	Warp	Fill.	Warp	Fill.
Control No. 1	P	3.85	2.02	1.69	1.27	1.40	0.97	1.67	1.54	1.42	1.45	1.50	1.42
A	P	[3] 3.04	2.18	1.68	1.33	1.38	1.04	[3] 1.74	1.48	1.31	1.23	1.52	1.33
B	P	[3] 4.10	2.59	1.68	1.59	1.46	1.21	1.61	1.60	1.31	1.16	1.50	1.38
C	P	5.09	2.59	1.73	1.59	1.56	1.23	1.67	1.43	1.33	1.16	1.54	1.37
D	B	-------	[1] 8.28	4.86	3.43	[3] 6.10	3.88	-------	[3] 2.86	2.24	2.31	[3] 2.54	2.35
E	B	[3] 17.34	[1] 8.29	4.05	3.12	[3] 4.28	3.45	[3] 2.72	[3] 2.76	2.10	2.16	[3] 2.58	2.16
F	B	[3] 16.86	[1] 6.15	3.77	2.84	[3] 3.83	2.42	[3] 2.82	[3] 2.52	2.15	2.32	[3] 2.50	2.29
G	B	[3] 17.27	[1] 6.42	3.67	2.81	[3] 4.12	2.38	[3] 3.17	[3] 2.70	2.14	2.30	[3] 2.42	2.34
H	P	3.45	2.21	1.62	1.30	1.36	1.04	1.62	1.73	1.28	1.27	1.45	1.21
Control No. 2	P	[3] 2.99	1.77	1.57	1.04	1.10	0.87	[3] 1.89	1.59	1.75	1.19	1.72	1.33
A	P	[3] 3.05	1.92	1.50	1.19	1.09	1.00	[3] 2.00	1.54	1.63	1.25	1.71	1.31
B	T	[3] 6.20	2.62	2.16	1.38	[3] 1.44	1.06	[3] 2.26	2.83	1.73	1.36	1.68	1.33
C	O	[3] 7.05	2.22	2.13	1.18	[3] 1.54	.99	[3] 3.04	1.68	2.50	1.25	2.78	1.33
D	P	[3] 3.14	1.96	1.60	1.22	1.20	1.00	[3] 1.90	1.49	1.78	1.16	1.80	1.26
E	P	[3] 3.27	1.96	1.58	1.27	1.20	1.04	[3] 2.03	1.52	1.67	1.13	1.67	1.33
F	O	[3] 7.38	2.54	2.29	1.35	[3] 1.66	1.18	[3] 3.38	1.56	2.50	1.24	2.70	1.30
Control No. 3	S	10.50	8.40	5.43	5.68	5.03	4.38	1.90	1.75	1.61	1.24	1.86	1.41
A	S	10.08	7.57	5.38	4.90	-------	3.75	1.80	1.60	1.54	1.25	1.67	1.25
B	O	6.49	3.53	5.28	3.82	3.42	2.82	2.38	1.10	2.76	1.29	2.38	1.44
C	S	11.51	7.89	5.16	5.37	5.05	4.42	1.79	1.55	1.58	1.32	1.88	1.46
D	S	11.26	7.46	5.76	5.79	6.12	4.41	1.82	1.58	1.62	1.28	1.95	1.35
E	O	7.17	3.70	5.15	3.55	-------	2.75	2.55	1.14	2.60	1.09	2.02	1.42
Control No. 4	T	9.48	5.55	5.82	4.43	[3] 4.20	3.14	1.75	1.28	1.58	1.22	[3] 1.46	1.32
A	T	9.93	6.17	5.86	5.38	[3] 4.26	3.51	1.77	1.34	1.57	1.20	[3] 1.50	1.28
B	O	8.41	3.66	6.35	3.92	[3] 4.09	2.36	2.34	1.14	2.34	1.28	[3] 2.02	1.13
C	T	9.43	5.50	5.93	4.76	[3] 4.09	3.16	1.66	1.37	1.58	1.22	[3] 1.47	1.28
D	T	10.58	5.61	6.30	4.57	[3] 4.33	2.83	1.69	1.24	1.54	1.19	[3] 2.28	1.30
E	O	8.92	3.70	6.81	4.03	[3] 4.16	2.76	2.44	1.07	2.54	1.34	[3] 2.11	1.42
F	O	9.24	3.71	6.80	4.16	[3] 4.36	2.41	2.28	1.16	2.28	1.36	[3] 1.34	1.37
5	T	10.19	5.87	7.25	5.29	[3] 4.33	3.26	1.61	1.26	1.71	1.30	[3] 1.34	1.43
5B	O	9.22	4.26	7.44	4.74	[3] 4.29	3.03	2.16	1.11	2.65	1.40	[3] 1.91	1.31

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[1] Weaves: P, Plain; B, 2 x 2 Basket; T, 3/1 Twill; O, Oxford; S, Sateen.

[2] Without resin.

[3] Tails of test specimens were folded to facilitate tearing action.

Table 14.—*Summary of nominal and actual relative weights and cover factors in finished and resinated USDA experimental fabrics*

Sample No.	Total relative weight[1]			Relative cover factor[2]					
		Actual		Nominal		Actual			
						(SR)		(RT)	
	Nominal	(SR)[3]	(RT)[4]	Warp	Fill.	Warp	Fill.	Warp	Fill.
Control No. 1	4.73	4.68	4.65	15.5	12.0	15.5	11.7	15.3	11.7
A	4.73	4.68	4.65	15.5	12.0	15.5	11.7	15.5	11.5
B	5.03	5.03	4.97	15.5	12.0	15.5	12.0	15.3	11.9
C	4.73	4.80	4.80	15.5	10.4	15.5	10.8	15.5	10.8
D	4.73	4.83	4.83	15.5	10.4	15.5	11.0	15.3	11.1
E	5.03	5.10	5.13	15.5	12.0	15.3	12.6	15.5	12.6
F	4.73	4.78	4.78	15.5	12.0	15.3	12.5	15.5	12.3
G	4.67	4.71	4.72	14.6	12.6	14.4	13.1	14.6	12.9
H	4.67	4.73	4.70	14.6	12.6	15.0	12.6	14.8	12.6
Control No. 2	4.34	4.31	4.31	20.0	9.9	19.9	10.0	19.9	10.0
A	4.34	4.31	4.27	20.0	9.9	19.8	10.1	19.8	9.8
B	4.34	4.33	4.31	20.0	9.9	19.8	10.2	19.9	10.0
C	4.34	4.36	4.31	20.0	9.9	20.2	10.0	20.0	9.8
D	4.45	4.47	4.47	20.0	9.8	19.8	10.3	20.0	10.0
E	4.32	4.37	4.37	20.0	9.0	19.8	9.6	19.8	9.6
F	4.32	4.47	4.39	20.0	9.0	20.2	9.8	19.9	9.6
Control No. 3	9.51	9.80	9.58	27.7	13.9	28.1	14.7	27.7	14.2
A	9.51	9.68	9.58	27.7	13.9	27.9	14.4	27.7	14.2
B	9.51	9.51	9.42	27.7	13.9	27.7	13.9	27.9	13.4
C	93.50	9.60	9.53	26.6	14.2	26.9	15.0	26.9	14.7
D	9.01	9.06	9.01	26.6	12.9	26.9	12.9	26.6	12.9
E	9.01	8.81	8.81	26.6	12.9	26.6	12.1	26.6	12.1
Control No. 4	11.40	11.47	11.40	29.9	14.2	30.2	14.2	30.2	13.9
A	11.40	11.53	11.47	29.9	14.2	30.5	14.2	30.2	14.2
B	11.40	11.60	11.46	29.9	14.2	30.7	14.2	30.7	13.7
C	11.00	11.39	11.13	28.4	14.2	29.7	14.4	29.2	13.9
D	10.66	10.93	10.73	28.4	12.9	29.4	12.9	29.2	12.4
E	11.00	11.27	11.20	28.4	14.2	29.4	14.2	29.4	13.9
F	10.66	10.87	10.80	28.4	12.9	29.4	12.6	29.4	12.4
5	10.81	11.16	10.89	25.8	14.2	23.8	14.4	23.5	13.7
5B	10.81	11.30	11.17	25.8	14.2	24.2	14.4	24.0	14.2

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[1] Total relative weight = (warp yarns per inch divided by warp yarn number) + (filling yarns per inch divided by filling yarn number)

[2] Relative cover factor = yarns per inch divided by $\sqrt{\text{yarn number}}$

[3] SR—Sans Resin

[4] RT—Resin Treated

Table 15.—*Summary of nominal and actual percentage change*[1] *in relative weights and cover factors in finished and resinated USDA experimental fabrics*

	% Change in total relative weight			% change in cover factor					
		Actual		Nominal		Actual			
						(SR)		(RT)	
Sample No.	Nominal	(SR)[2]	(RT)[3]	Warp	Fill.	Warp	Fill.	Warp	Fill.
1A	----------	----------	----------	----------	----------	----------	----------	+ 1.3	— 1.7
B	+ 6.3	+ 7.5	+ 6.9	----------	----------	----------	+ 2.6	----------	— 1.7
C	----------	+ 2.6	+ 3.2	----------	—13.3	----------	— 7.7	+ 1.3	— 7.7
D	----------	+ 3.2	+ 3.9	----------	—13.3	----------	— 6.0	----------	— 5.1
E	+ 6.3	+ 9.0	+10.3	----------	----------	— 1.3	+ 7.7	+ 1.3	+ 7.7
F	----------	+ 2.1	+ 2.8	----------	----------	— 1.3	+ 6.8	+ 1.3	+ 5.1
G	— 1.3	+ .6	+ 1.5	— 5.8	+ 5.0	— 7.1	+12.0	— 4.6	+10.2
H	— 1.3	+ 1.1	+ 1.1	— 5.8	+ 5.0	— 3.2	+ 7.7	— 3.3	+ 7.7
2A	----------	----------	— .9	----------	----------	----------	----------	----------	— 2.0
B	----------	----------	----------	----------	----------	----------	+ 2.0	----------	----------
C	----------	+ 1.2	----------	----------	----------	+ 1.5	----------	----------	— 2.0
D	+ 2.5	+ 3.7	+ 3.7	----------	----------	----------	+ 3.0	----------	----------
E	----------	+ 1.4	+ 1.4	----------	— 9.1	----------	— 4.0	----------	— 4.0
F	----------	+ 3.7	+ 1.8	----------	— 9.1	+ 1.5	— 2.0	----------	— 4.0
3A	----------	— 1.2	----------	----------	----------	— .7	— 2.0	----------	----------
B	----------	— 3.0	— 1.7	----------	----------	— 1.4	— 5.4	+ .7	— 5.6
C	— 1.7	— 2.0	----------	— 4.0	+ 2.1	— 4.3	+ 2.0	— 2.9	+ 3.5
D	— 5.3	— 7.6	— 5.9	— 4.0	— 7.2	— 4.3	—12.2	— 4.7	— 9.1
E	— 5.3	—10.1	— 8.0	— 4.0	— 7.2	— 5.3	—17.7	— 4.7	—14.8
4A	----------	+ .5	+ .6	----------	----------	+ 1.0	----------	+ 1.6	+ 2.2
B	----------	+ 1.1	+ .5	----------	----------	+ 1.6	----------	— 3.3	— 1.4
C	— 3.5	— .7	— 2.4	— 5.0	----------	— 1.6	+ 1.3	— 3.3	----------
D	— 6.5	— 4.7	— 6.8	— 5.0	— 9.1	— 2.6	— 9.2	— 2.6	—10.8
E	— 3.5	— 1.7	— 1.8	— 5.0	----------	— 2.6	----------	— 2.6	----------
F	— 6.5	— 5.2	— 5.3	— 5.0	—99.0	— 2.6	—11.3	— 2.6	—10.8
5	— 5.2	— 2.7	— 4.5	—13.7	----------	—21.2	+ 1.4	—22.2	— 1.4
5B	— 5.2	— 1.5	— 2.0	—13.7	----------	—19.9	+ 1.4	—20.5	+ 2.2

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[1] Based on the value of these parameters in the control fabric.

[2] SR—Sans Resin.

[3] RT—Resin Treated.

Table 16.—*Summary of drape coefficients (% F) of resinated USDA experimental fabrics*

Sample No.	Drape coefficient (% F)	Sample No.	Drape coefficient (% F)
Control No. 1	58.3	Control No. 3	65.0
A	60.8	A	66.7
B	59.3	B	74.8
C	60.2	C	68.0
D	53.8	D	65.6
E	56.4	E	71.6
F	55.6		
G	54.8		
H	60.0		
Control No. 2	60.6	Control No. 4	76.5
A	61.7	A	70.6
B	53.3	B	84.1
C	59.1	C	77.2
D	61.2	D	72.9
E	60.5	E	83.6
F	58.6	F	78.6
		5	71.5
		5B	80.1

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